AIRPLANE MAINTENANCE

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AIRPLANE MAINTENANCE

A Textbook for Airplane Mechanics

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PREFACE

This text is prepared for the following purposes:

1. The training of mechanics for repair stations of airlines.
2. To serve as a reference book for repair-station operators.
3. To be a text and reference for the use of the mechanics of the armed forces.

The need of a text of this type became obvious when a study was made for the revision of "Airplane Construction and Repair." This study revealed that at the present stage of development of airplanes in this country, there are *two general classes* of airplane mechanics:

1. *The private operator, and the mechanics employed by the private operator or employed in small repair shops catering to the private operator.* This class of mechanic is concerned principally with the construction and repair of small airplanes of the wood, wire, steel-tubular, and fabric types.
2. *Mechanics employed in large repair stations of national and international airlines, and mechanics in the major depots of the Army Air Forces and of Naval Aviation.* This class of mechanic is concerned exclusively with the repair, overhaul, and maintenance of large all-metal aircraft.

It was decided that for class 1, "Airplane Construction and Repair" needed very little if any revision at the present time. This text, however, does not suit the requirements of class 2—a class which did not exist when "Airplane Construction and Repair" was written. It was accordingly decided to write a new text, "Airplane Maintenance," expressly for the purpose of the mechanic whose work is primarily on metal airplanes.

In the preparation of "Airplane Maintenance" the authors have consulted more than fifty experts, including airplane superintendents of maintenance, manufacturers, field experts, etc. The response of these men to requests for advice and assistance has been extremely gratifying. Credit is given to them and to their organizations throughout the text. The following is a list of personnel, not mentioned elsewhere in the text, for whose assistance the authors express their sincere appreciation:

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CONTENTS

PAGE
PREFACE v

JOB UNITS ix

CHAPTER I
QUALIFICATION OF AN AIRPLANE MECHANIC 1

CHAPTER II
REPAIR SHOPS AND EQUIPMENT 7

CHAPTER III
AIRPLANE PARTS AND EQUIPMENT: STRUCTURAL TYPES AND NOMENCLATURE: 20

CHAPTER IV
STATIC AND DYNAMIC TESTING 40

CHAPTER V
PROPERTIES AND USES OF METALS. 57

CHAPTER VI
MAINTENANCE OF METALS 74

CHAPTER VII
AIRCRAFT-MAINTENANCE WELDING. 105

CHAPTER VIII
AIRCRAFT-WELDING METHODS. 137

CHAPTER IX
BASIC PRINCIPLES OF THIN-SHEET-METAL STRUCTURES. . . 188

CHAPTER X
FORMING THIN SHEET METALS FOR REPAIRS 212

CHAPTER XI
RIVETS AND RIVETING 223

CHAPTER XII PAGE
REPAIR OF THIN-SHEET-METAL STRUCTURES 243

CHAPTER XIII
REPAIR OF WOOD, WIRE, AND FABRIC STRUCTURES 273

CHAPTER XIV
MAINTENANCE CLEANING 296

CHAPTER XV
MAINTENANCE OF PROPELLERS 306

CHAPTER XVI
SERVICING OF SHOCK ABSORBERS, BRAKES, AND TIRES . . . 323

APPENDIX
SAMPLES OF TROUBLE AND INSPECTION REPORTS 341

INDEX 351

JOB UNITS

PAGE
1. Study of Airplane Structural Types by Observation 33
2. Library Study of Structural Types of Airplanes 37
3. Cadmium Plating 98
4. Effect of Heat on Steels 101
5. Identification of Aluminum Alloys 102
6. Manipulation of Welding Torch 172
7. Handling of Filler Rod 173
8. Alignment 174
9. Corner Welding 175
10. Rosette Weld and Washer Weld 176
11. Tube Welding—Butt Joint 177
12. Plate to Tube Weld 177
13. Cluster-joint Welding for Tubes 178
14. Seven-tube Cluster Weld 178
15. Repair Weld 180
16. Brazed Joint 180
17. Sleeve Joint 181
18. Aluminum-sheet Welds 181
19. Aluminum-sheet Weld 182
20. Fishplate Welding 183
21. Motor-mount Ring 183
22. Making Lap-riveted Joint 240
23. Making Butt-riveted Joint 241
24. Testing Riveted Joints for Strength 241
25. Other Job Units 242
26. Repair of Corrugated Stressed Sheets 246
27. Repairs of Smooth Stressed Skin 248
28. Repair of Strut 249
29. Replacement of an Aluminum-alloy Strut 251
30. Repair of a Stringer 251
31. Repair of a Semistressed Fuselage 253
32. Standard Repair of Small Holes (¼ In. to 1 In. in Diameter) in Thin Sheets 255
33. Repair of Crack in Engine Cowl, Fillet, Wing Tip, and Other Nonstressed Sheets 256
34. Repair of a Break in a Stressed Fuselage 257
35. Repair of the Fuselage Bottom Skin 257
36. Repair of Metal Trailing Edge of Fabric-covered Surfaces 258
37. Repair of a Spar Web 259
38. Repair of the Flange of a Beam 260
39. Repair of the Leading Edge of a Wing 262

PAGE
40. Repair of Metal Nose Covers on Fabric-covered Wing Flaps . . . 263
41. Repair of Metal-covered Stabilizer. 263
42. Repairing Seaplane Floats 265
43. Repair of a Torque Tube. 270
44. Repair of Ribs 271
45. Repair of Semimonocoque Engine Nacelle 271
46. Repair of Dent in a Steel Tubular Strut 271
47. Fabric Patching. 278
48. Loop Terminals in High-carbon Tinned Aircraft Wire 284
49. Soldered Cable Terminal. 286
50. The Navy Splice 288
51. Roebling Splice and Test of Cable Terminals. 291
52. Report on Propellers. 317
53. Checking Propeller Track 318
54. Checking Track of Metal Propellers (U.S. Air Corps Method) . . 319
55. Balancing of Propellers. 320
56. Servicing Aerol Shock Absorbing Struts 323
57. Servicing Oleo-spring Strut 324
58. Servicing Bendix Pneudraulic Shock Struts. 324
59. Adjustment of Bendix Mechanical Brakes 329
60. Adjustment of Bendix Hydraulic Brakes. 330
61. Service of Goodyear Airwheel Hydraulic Disk Brake. 331
62. Maintenance Hints 334
63. Mounting and Demounting Low-pressure Airplane Tires on Drop-center Rims. 336
64. Mounting and Demounting General Streamline Airplane Tires . . 337

AIRPLANE MAINTENANCE

CHAPTER I

QUALIFICATION OF AN AIRPLANE MECHANIC

The principal qualifications of an airplane mechanic may be listed as follows:

1. Responsibility.—The primary object to be attained in a course of instruction for airplane mechanics is the training of men not only to do their work *correctly* and *intelligently*, but to assume full *responsibility* for the *accuracy* and *thoroughness* of their work. In no other trade is this sense of responsibility so essential.

The federal government, as well as the flying public, recognizes the airplane mechanic as a responsible expert of the highest order. Rigid qualifying examinations separate the well trained from the poorly trained—but responsibility, closely associated with character, cannot be determined by examination. A test is not only disastrous to the candidate but to others as well. One false irresponsible step on the job, and the mechanic's career is "washed out."

During the training period is the time to develop a high sense of responsibility. *The student, from the first, should establish for himself a record of responsibility and guard this record zealously throughout his career.*

2. Technical Skill.—Reliability is of little value if the work is not accomplished intelligently. A mistake, for example, in the apparently simple job of washing an airplane, of using the wrong washing solution, may cause important parts of the structure to corrode. A tiny hairline crack in the metal structure or in the propeller may have no meaning to the untrained mind, but to the skilled mechanic, these microscopic lines are giant bill boards of danger.

Intelligence on the job requires training—reliable, thorough, and careful training—in all phases of the work. The best place to obtain this training is in one of the many excellent aviation schools, public or private, day school or night school.

3. Education.—It is assumed in this text, which is written for the average trade school for airplane mechanics, that the student is possessed of a fair knowledge of the fundamental sciences, such as mathematics, physics, etc. The equivalent of two years or more of high school is desirable. And even college graduates, especially in engineering, find it desirable to take vocational training in aviation in preparation for many of the engineering positions available in the aircraft industry.

While a general course in aviation is not necessary for the airplane mechanic, a knowledge of elementary aerodynamics and other phases of aviation training is desirable. Many excellent elementary texts on aerodynamics are available.

4. Specialized Training.—The airplane mechanic should have specialized training in:

1. Care and use of shop equipment and tools.
2. Repair-shop routine and inspection routine.
3. Handling of airplanes in the hangars and on the line.
4. Safety from accidents and fire.
5. The names of airplane parts, and the functions of the parts.
6. The types of structures in airplanes and the peculiarities of each type.
7. The materials used in aircraft structures; their properties, treatment, and uses.
8. Fabrication of materials, welding, riveting, forming, etc.
9. Basic principles of the strength of thin-sheet-metal structures.
10. Working, forming, etc., of thin sheet metals for repairs. A knowledge of woodwork is required in making molds for forming thin sheets.
11. Repair of wooden members. This requires a knowledge of woodworking and gluing.
12. Wire work, such as making terminals, splices, etc.
13. Fabric work, such as cutting, sewing, and doping fabric surfaces.
14. Adjusting, service, and minor repair of metal propellers.
15. Cleaning exteriors, interiors, and the various parts of the airplane, together with routine lubrication of moving parts.
16. Servicing and adjusting of brakes, tires, wheels, shock absorbers, controls, hydraulic and electrical systems, etc.
17. The detailed inspection of all airplane parts.

5. Knowledge of Structures.—Airplane structures are the most carefully and scientifically designed of all engineering structures. *The structure must be light yet strong, durable, and safe.* Many parts of the structure are designed for as many as a dozen or more possible loading conditions in flight, in landing, and on the ground.

There is a scientific reason for each peculiarity of the structure. This reason may not be obvious to anyone except those concerned with the design. It is apparent therefore that *changes should not be made in a structure, without the instruction from the proper source—the engineering department.*

Major repairs are design problems, and hence must be made under instructions, as though the airplane were in the factory under construction.

6. Government Regulations.—The aircraft industry is very carefully supervised and regulated by the federal government. While there are many ways in which the government regulations apply, only those parts concerning the airworthiness of the airplane directly apply here. The Civil Aeronautics Administrator of the U. S. Department of Commerce is the official concerned. The Civil Aeronautics Board, a five-man, independent, quasi-judicial commission, adopts the regulations and exercises inspection over them by means of a corps of safety investigators who function when accidents occur.

The regulations that apply to the repair and maintenance of airplanes are known as the CAR (short for Civil Air Regulations), which is published in a large number of "parts," all catalogued by a decimal breakdown into individual regulations. There are in excess of 25 of the CAR, numbered irregularly from Part 01. to Part 99. There are parts that apply directly to the aircraft mechanic and the maintenance and repair of the airplane. Other parts apply to the engine mechanic and his work. In addition there are Regulations of the Administrator, published in parts numbered from 501 to 601; only Part 501, Aircraft Registration Certificates, will apply to the mechanic and his work.

The following parts apply to the aircraft mechanic:

Part 501. Aircraft Registration Certificates.
01. Airworthiness Certificates.
04. Airplane Airworthiness.
15. Aircraft Equipment Airworthiness.
18. Maintenance, Repair and Alteration of Certificated Aircraft, etc.
24. Mechanic Certificates.
52. Repair Station Rating.
98. Definitions.
Section 60.32. Identification marks.

There are also manuals to go with some of these parts. Each manual is numbered the same as the CAR part to which it applies. Manual 104 is an explanation of CAR, Part 04. Likewise Parts 15, 18, and 52 have accompanying manuals.

Every student should have a copy of all the above-listed parts and their manuals. Copies can be obtained at no charge from the Civil Aeronautics Administrator (Publications and Statistics Division), Washington, D. C., by stating the purpose for which they are needed. Studying for certification examinations is a valid reason for getting them. In due course, all parts (manuals are issued without charge by the CAA) will be on sale at the Government Printing Office, Washington, D. C., most of the parts at nominal cost. Anyone who wishes to get those parts that are not directly needed will have to buy them. A complete list and prices will be sent by the administrator on request, or the current number of the *Civil Aeronautics Journal* can be consulted for their status. This journal is a monthly periodical open to subscription.

Complete familiarity with the above-listed parts of the CAR is an essential for the aircraft mechanic. He must begin his education by studying them and must continually refer to them and the manuals throughout his whole working life. Frequently amendments are issued and these must be secured and entered in his copy of the proper part. Watching the *Journal* is the best way to keep informed on pertinent amendments.

Manual 18, Maintenance, Repair and Alteration of Certificated Aircraft, Aircraft Engines, Propellers and Instruments, is a most prolific source for useful information. It has many illustrations of typical repairs to damage, structure, as well as pertinent data on how to maintain, repair, or alter aircraft and comply with the CAR in all ways.

References

1. Vocational Training for Aviation Mechanics, *Bulletin* 142, Trade and Industrial Series 40, Federal Board of Vocational Education, Washington, D. C. Ask for the latest issue. This bulletin has no information for the student. It is for the use of teachers. One library copy per school is sufficient.

2. Regulations of the Administrator, Part 501, Aircraft Registration Certificates.

3. Civil Air Regulations.

Part 01. Airworthiness Certificates.
04. Airplane Airworthiness.
15. Aircraft Equipment Airworthiness.
18. Maintenance, Repair and Alteration of Certificated Aircraft, etc.
24. Mechanic Certificates.
98. Definitions.

Manuals for Parts 04, 15, and 18.

4. "The Aircraft Year Book" (for the current year), Aeronautical Chamber of Commerce of America, Inc., New York.

Questions an Airplane Mechanic Should Be Able to Answer[1]

(Air Commerce Regulations)

1. How often must a certificated airplane be inspected? By whom?

2. What lights must be carried on a plane carrying passengers for hire at night?

3. What entries are required in the airplane and engine log of a certificated airplane?

4. May an uncertificated mechanic work on a certificated airplane?

5. May a certificated mechanic work on an uncertificated airplane?

6. What experience is necessary to be eligible for an engine mechanic's certificate?

7. What experience is necessary to be eligible for an airplane mechanic's certificate?

8. What report must be submitted to the Department of Commerce after an accident to a certificated airplane?

9. If you fail on this examination, how long must you wait before reapplying?

10. How long does a mechanic's certificate remain in force?

11. What is necessary to renew it?

12. Give five reasons for the suspension or revocation of a mechanic's certificate.

13. Where should the log book of a certificated airplane be kept?

14. What special equipment must be in a plane making a trip over water?

15. How often is a line inspection required on a certificated airplane?

16. Must a certificated engine mechanic be experienced in the maintenance of ignition system?

17. Name eight items that are included in a daily line inspection.

18. Are safety belts required on both closed and open cockpit airplanes?

19. What would be the meaning of a registration reading *NR*3046?

20. Is a compass ever required on a certificated airplane?

21. What is the age requirement for a mechanic's certificate?

22. What engine instruments are required on a certificated airplane?

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[1] This set of questions is from Ref. 1. They are listed under the heading Sample Mechanics' Examination Questions.

23. What safety equipment is required on certificated aircraft carrying passengers for hire?

24. May a certificated mechanic ride in the copilot's seat?

25. What civil penalty may be imposed for a violation of the terms of an airman's certificate?

26. What are the markings for certificated aircraft?

27. What requirements must be met before carrying passengers for hire in an airplane which has been seriously damaged?

28. When must a mechanic carry his certificate?

29. May a citizen of a foreign country hold a mechanic's certificate?

30. Must an applicant for mechanic's certificate be able to read, write, and speak the English language before receiving a certificate?

31. Is anyone other than a certificated mechanic authorized to sign the log book of a certificated airplane?

32. How do you tell the difference between a certificated and uncertificated airplane?

33. What are the sizes of the letters and numbers required on the wings of an airplane?

34. What are the requirements relative to the placarding of baggage compartments in certificated aircraft?

35. When must a navigation summary report be submitted to the Secretary of Commerce?

36. How shall a serious accident, which results in serious injury to persons, be reported?

37. What procedure is necessary in repairing a certificated aircraft which has been seriously damaged before the certificate can be continued or be renewed?

38. If a component is damaged more than 50 per cent, what procedure is necessary?

39. Does it make a difference if the repairs are made at an approved repair station?

40. What constitutes a line inspection?

41. When is a first-aid kit necessary on a certificated airplane?

42. Is a fire extinguisher on all certificated aircraft a requirement?

43. When is a gasoline gauge required on a certificated airplane?

44. Who is responsible for signing the log when repairs are made to a certificated airplane?

45. What equipment and facilities are required in order for a repair station to be approved to repair a welded-tube structure, excluding fittings?

46. Is it necessary to carry the log book in a certified airplane when making cross-country trips?

47. Are electric landing lights required on certified airplanes only in transportation of mail at night?

48. What is meant by a periodic inspection?

49. When is a periodic inspection made?

50. Is an applicant for mechanic's certificate required to pass a practical as well as a theoretical examination?

CHAPTER II

REPAIR SHOPS AND EQUIPMENT

Shops for the alteration and repair of certificated aircraft must in most cases meet the requirements of the Civil Aeronautics Administration as laid down in the Civil Air Regulations, Part 52. Shops authorized to make repairs are called approved repair stations. Detailed information as to getting this approved repair station standing is set forth in the above-mentioned part of the CAR and in the manual of the same number.

7. Approved Repair Stations.—Generally speaking, a repair station is approved for only certain classes of work. Those listed by the Administration are as follows:

1. Aircraft welded steel tube structure.
2. Aircraft wooden structure (not including box and laminated spars, wood-covered fuselages or wings and control surfaces).
3. Aircraft fabric covering.
4. Aircraft wood-covered fuselages, wings, and control surfaces, and box and laminated spars.
5. Aircraft steel fittings.
6. Aircraft aluminum-alloy structure (not including fittings).
7. Aircraft aluminum-alloy fittings.
8. Aircraft assembly.
9. Aircraft aluminum-alloy propeller blades and steel hubs.
10. Aircraft wooden propellers.
11. Aircraft engines.
12. Aircraft instruments.

In the following paragraphs are presented the general specifications for shop space and equipment necessary in an approved repair shop. Only special items will be covered, and information usually found in tool and equipment catalogues will be omitted since the student may obtain this information from tool and equipment manufacturers free of charge. Likewise, the detail of the CAR is omitted, since these things may be obtained in Government bulletins free of charge or for a nominal sum. (See References at the end of the chapter.)

8. Shop and Office Space.—It is possible that an approved repair station for the most essential repairs on airplanes could be installed in a space as little as 3,000 sq. ft., provided there is some additional space in which an airplane, either dismantled or fully erected, could be stored while its parts were undergoing repair. Such a limited area would, however, be very cramped. *It would be far better if approximately a total of* 10,000 *sq. ft. were available for a small, complete repair station that would be able to handle about three airplanes or components at a time.*

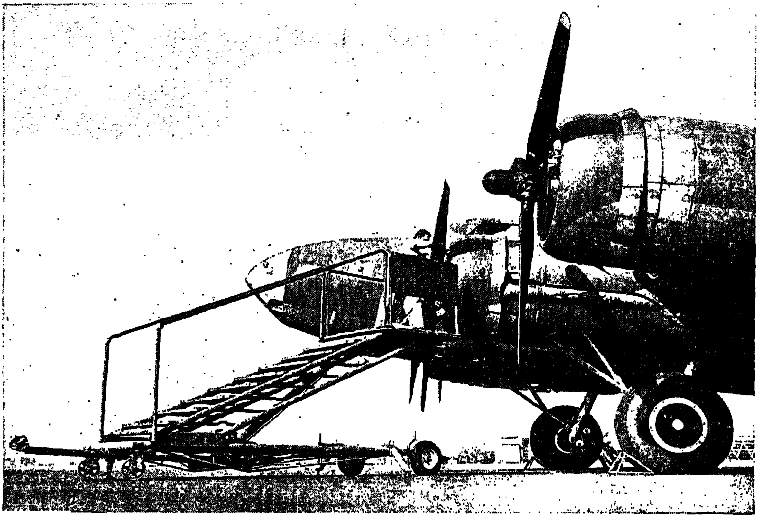

FIG. 1.—Aerostand, an adjustable service stand which can be easily moved about. (*Courtesy of Pacific Service Corporation.*)

Office space should be closed off from the erection shop wherein accurate records can be kept of all work done on licensed airplanes. Close to the erection shop is probably the best place for office space for much work will be completed right in this shop and never go any farther.

9. Assembly Hangar and Equipment.—The assembly hangar or space must be large enough to house the largest airplane likely to be worked on. It must also have doors that will open far enough to allow the airplanes to be taken in and out unless the airplanes are to be removed to the airport to be assembled. The assembly hangar should be preferably on the airport. The rest of the repair station can be remote from the airport if desired, but it is, of course, of considerable value to have it all under the same roof or very close together.

The assembly hangar of a completely equipped repair shop will have as a minimum equipment:

1. *Ladders*, preferably of the step type, sufficiently high to be able to set up and work above the highest wing likely to be worked on.

2. *Several platforms* of minimum of 4 by 6 ft., and preferably larger, made up of welded-steel angles or tubes with a good substantial wooden floor and mounted on casters that can be raised in order to set the platform solidly on the ground. These should be available in several heights, the lowest being about 4 ft. from the ground, the highest possibly as high as 8 ft. The higher one should have a railing on at least two sides.

Figure 1 illustrates an adjustable service stand that has much merit. A hydraulic cylinder allows it to be readily extended over a wide range of heights and its design is such that it will fit over many parts of the airplane and provide comfortable working facilities at locations that would otherwise be awkward to reach.

3. There should also be an *adjustable stand of the tripod type* in order to regulate the height of the tail when setting the plane up in rigger's flying position.

4. *Short pedestal stands* should also be available to support the airplane by the axle or jack pads so that the tires are off the ground whenever making actual adjustments to the rigging of the airplane.

5. *Plumb bobs with strings* 10 *to* 12 *ft. long*, which can be tied to the end of a light pole, such as a one-piece bamboo fish pole, should be available. There should also be several plumb bobs that are separate, for use in confined places. Using the plumb bob on the fish pole is very simple as the pole is merely leaned against the leading edge of the wing or against the point where it is desired to hang the plumb bob. Measurements can be readily made, and the plumb bob can be moved from point to point very rapidly.

6. *Several sizes of precision levels and level protractors* should be available.

7. *Several good light-weight straightedges* about 4 ft. to 12 ft. in length should be available. It is well to make these straightedges laminated in order to minimize warping. They should be very carefully protected against damage; and it is well to paint them a distinguishing color so that they are not likely to be cut up by uninformed persons.

8. *A minimum of three scales*, two of them having a capacity of not less than 2,000 lb. each, should be available. Scales should be preferably of the type on which the load is off of the fulcrums except during the actual process of weighing. The third scale can be of a lighter type with a capacity of 500 lb. Platform-type scales are most suitable, the heaviest scales having the largest practicable platform and still to be fairly portable. For airplanes weighing more than about 4,000 lb., a lever weighing system can be rigged up with a little ingenuity. Inclined planes or ramps should be avail-

able so that an airplane can be rolled up onto the scales for weighing. The scale equipment is not essential, but it is a highly desirable part of any repair-shop equipment. It is excellent routine, whenever making changes or major overhaul or repairs, to weigh the airplane first, whenever possible, and determine its center of gravity position, repeating the process again upon completion of assembly in order that a complete record be available of the change in weight and position of the center of gravity. This procedure will save many arguments with both the customer and the Department of Commerce Inspectors.

It is excellent practice to weigh every airplane periodically and whenever the structural weight is getting too great to check through the machine carefully, removing excess material that has been put in. It is surprising how rapidly an airplane grows in the day-to-day operations. This is so because of the constant "beefing up" of parts in order that they will either last longer or can be maintained easier. If allowed to go without restraint, the airplane will become overloaded, thereby violating its airworthiness license. The airplane may even, under certain circumstances, become so overloaded as to become very dangerous.

The assembly hangar should have a concrete floor that is dry and well finished.

10. Dope and Fabric Rooms.[1]—It will be necessary for several compartments to be definitely closed off from the rest of the main space for particular reasons. The *dope shop*, which should be a minimum of about 500 or 600 sq. ft. with a major diagonal dimension of about 45 ft., must be tightly enclosed so it can be readily heated and so it can be protected against fire hazards. For a small shop the dope shop can also be equipped for fabric work, but this would limit output considerably, necessitating that work be scheduled in this place by doing all covering and then all doping, which might be quite a disadvantage when trying to get out a repair of a whole airplane.

The dope shop must be arranged with a heating source that will heat to a temperature of not less than 75°F. under the most severe weather conditions likely to be encountered. At the same time adequate ventilating equipment must be put in that will allow an air change in not more than every three minutes. *Certain localities have special laws covering the installation of dope shops. It is well to investigate local conditions before building one.* In any case, whatever heating system is adopted must be outside-fired by having a remote steam boiler or an air-heating furnace well away from the doping room. Steam radiators in the room itself are satisfactory, but if hot air is brought in, it should be brought in and distributed directly under the ceiling. The discharge from the room should be by means of a pressure-type, nonsparking fan (discharging into open air) driven by an electrical motor, preferably of the squirrel-cage type with a fumetight casing. The fan must be of a kind that can be readily cleaned; and in addition a fine copper screen should be between the fan and the room to prevent any possibility of flareback should the gases be ignited outside.

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[1] See also Chap. XIII.

The lights in the dope room must be in vaportight receptacles and all electrical switches must be outside the room. There should be no power plugs exposed in the room although in an extreme case a power plug might be installed overhead. It is a far better practice for jointless extension cords for any electrically driven portable tools to be carried clear out of the room, and plugged in outside.

Another excellent alternate is to use air tools entirely. If so, brass connectors must be used in order to prevent accidental sparking which might occur if steel pipe and connectors were to be used. The floor must be either wood and covered with linoleum, industrial carpet, or some fibrous material, and should never be concrete for fear that a spark might be thrown from a dropped tool, shoe nail, or other metal objects. *There should be at least one good door swinging out and held closed by a spring so that a rapid exit from the room is possible; and CO_2 type of fire extinguishers should be available immediately outside the door.*

11. Heat-treating Equipment.[1]—Heat-treating apparatus will vary with the immediate needs and location of the shop in question. In some localities commercial heat-treating concerns are available who can handle anything on specification. In other localities no such facilities are available and must be provided by the repair shop itself. In any event it will always be necessary to have rivet-heat-treating apparatus for the heat treatment of rivets. A small electric furnace using either a muffle or salt pot is satisfactory. Automatic temperature control must be fitted, and it is highly desirable that a temperature recorder be installed as well, in order to allow a check-back on the temperatures at any time. Usually the temperature controller and recorder are built into one machine. For the heat treatment of major parts and where such parts are not production items, it is best to have some type of salt bath and a fairly large container heated by either gas or oil furnace. If there is a fair volume of salt, hand regulation of temperature will be adequate, but in any case a record of the temperature should be kept. *Hand temperature regulation will be satisfactory only if constant attention is paid to the bath by a responsible experienced man.*

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[1] See also Chap. VI.

The salt mixture recommended is equal parts of sodium nitrate and potassium nitrate. This mixture is preferable as it is not only satisfactory for the heat-treating temperatures for aluminum alloys but also solidifies at a low enough temperature to allow annealing of them. Very close regulation of temperature must be exercised. For instance, when the 24*S* alloys are being treated, the temperatures must be held at 930°F. with a maximum tolerance of ±5°F. Anything over 5° above the recommended temperature will blister the material, and under 5° below that temperature, the heat treatment will not be satisfactory. For the 17*S* alloys the controlling temperature is 940°F. with a −5° and a +10° tolerance, the same remarks applying to higher or lower temperatures.

If salt baths are used, provision must be made thoroughly to wash the heat-treated parts after treatment. Warm water should be used if possible. Rivets should never be immersed in the salt, but held in closed-end tubes that are set into the bath. *Quenching must always be done in cold water.*

If iceboxes are used to delay age hardening, care must be taken that the temperature inside is low enough to insure prevention of the precipitation hardening. *Rivets not kept at low temperature must be driven* 30 *min. of treatment except A*-17 *rivets which require no heat treatment.*

12. Sheet-metal Shop.[1]—Sheet-metal construction of airplanes is done with tools similar in character to those used in an ordinary tin or sheet-metal shop. Owing to peculiarities of aircraft materials it is necessary, however, that the tools be used with care, and kept in first-class condition. *The tools in some cases must be slightly modified to fit better the needs of the material.*

Every care must be taken to insure against scratching the metal, for *every scratch is a potential fatigue failure.* Scribers are accordingly taboo as layout tools. A pencil is used instead. *A*

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[1] See Chap. X for types and uses of small tools in sheet-metal shops.

center punch is never used except to start a drill. Other ordinary metal-shop practices must be modified in the airplane sheet-metal shop.

Material must be racked in such a manner that it can be taken off the racks without sliding over other material. *The aluminum alloys must never be stored with steel, and even the harder alloys should be segregated from the softer ones whenever possible.*

Polished maple-topped benches are probably the best surfaces to work on. Maple is hard enough so that metal chips do not imbed in it, and at the same time soft enough so that it does not tend to scratch the material. Some shops use paper-covered benches, others use linoleum covers, but both of these are subject to the criticism that chips imbed in them readily and will not brush off easily.

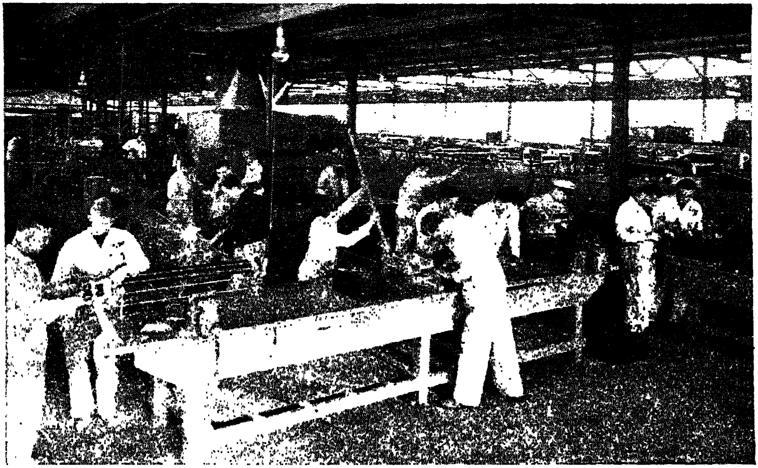

FIG. 2.—Sheet-metal shop: Parks Air College.

Great care must be taken with any metal-topped or metal-covered bench, table, or tool that might have sharp edges or burrs. All such imperfections must be smoothed with a fine file and no burrs allowed to remain.

Vises must be smooth-jawed with the edges most carefully rounded to a small radius, and polished. It is also necessary to use soft-metal protectors on the jaws in most cases, but even then rough or serrated vise jaws should not be used.

The air pressure for bull riveters (press) or for air guns must be closely regulated. Too high a pressure crushes and "dimples" the sheet and too low a pressure will result in work-hardening of the rivets. Rivet snaps and bucking bars must be free from burrs and sharp edges and should be polished.

Drilling of the strong aluminum alloys is done with normal twist drills sharpened in the usual manner. It is desirable that some attention be paid to the condition of the drill, removing burrs if necessary with an oil stone. The drill speed should be about three to three and a half times that for steel; and lard oil is the best lubricant. Carbon steel drills are entirely satisfactory.

Band saws and jig saws used to cut the strong aluminum alloys must be fitted with metal cutting blades and operated at about one half of the wood-cutting speed for best results. If a tooth is broken in a saw, that blade should not be used because a decided nick will be cut in the sheet and might be the start for a fatigue failure.

The squaring shear must be kept sharp and the blades adjusted to small clearance as otherwise the material will pull. When soft aluminum is being sheared, lard oil should be applied to prevent the aluminum from seizing onto the blades. The shear used for aluminum alloys should be restricted to that use, and never should it be used for steel.

Brakes for use with aluminum alloys must have a small radius on the blade. In spite of the relative softness and apparent ductility of these alloys, they are surprisingly brittle. The radius should never be less than the thickness of the sheet that will be used, and many mechanics make it about 0.1 in. for an 0.066-in. sheet. The blade, bed, and edge of the leaf or apron must be free from burrs, paint, dirt, and shavings.

Several types of rolls are used in the airplane sheet-metal shop. The three most common are the slip, beading, and edging rolls.

The *slip rolls* must be smooth, free of burrs, and properly adjusted to the thickness of the sheet to prevent their being sprung.

Beading rolls are used to run beads, stiffeners, or to form radii at or near joints. They are used most extensively in making fuel tanks. The rolls must be smooth, and the edges must be rounded to as large a radius as possible.

Edging rolls are used to turn the edge of a sheet in order to take out the wavy edge and also to make the finished seam lie up flat. The rolls ordinarily furnished with this machine are too sharp and must be ground to about a 1⁄16 in. radius.

Special rolls can be made up by the ingenious metal-shop mechanic to meet his particular needs.

The nibbling machine is not used very much with the aluminum alloys. It is invaluable, however, for the making of steel fittings from sheet stock.

A *nibbling machine* comes with one size of die and two punches marked the *A* and *B* punches, respectively. The *A* punch is a very close fit in the die, and is used for thin plate or materials which are tough or soft. In other words, it is suitable for use with 2S or 3S, 52S, thin 18-8 (stainless steel), 1020 (mild steel) steels under 0.049 in. in thickness. The *B* punch fits the die with some clearance, probably about 0.003 or 0.004 in. It is used on thick or brittle material, particularly on 4130 steel (chrome-molybdenum) and on 1020 or 18-8 that is over 0.049 in. thick.

The *throatless shear* is a very handy tool and can be used for the cutting of straight and irregular lines in all types of sheet metal. When working with the strong aluminum alloys care must be taken in its use for the driving roller or shear wheel is notched in order to propel the material through the machine. These notches nick the edge of the cut rather badly on one side and not quite as severely on the other. It is necessary to file out the nicks in order to insure against the possibility of fatigue failures, but with some care the amount of filing can be reduced materially.

For the making of forms, patterns, and bend blocks it is highly necessary that some type of woodworking machinery be available to the metal shop. A good heavy *band saw* is particularly valuable. A *circular saw* is desirable. If a regular woodworking shop is part of the repair plant, it is not necessary that there be special woodworking equipment in the metal shop.

A good *screw-cutting lathe* is an excellent piece of equipment. One of at least 11-in. size is preferable, not because really large work will have to be done, but such a lathe will be heavy and rigid enough to do rapid work. A *small hand milling machine* is also an excellent addition to any repair shop, with a good collection of cutters of various types. An indexing head is hardly ever needed, however.

13. Stock Room: Identification and Care of Materials.—One of the most important items in the aircraft shop is the identification and segregation of materials. Many and varied materials, in all states, must be kept in such a manner that no error can arise in their use. The designer has reasons for specifying a particular material for every part. Construction of that part must be of the required material in the required state. The repair man must conform to these requirements as well.

All shops will include, in materials on hand, ferrous metals, ranging in alloys from 1020, cold-rolled carbon steel, through 1025 to 4130X chrome-molybdenum steel. Occasionally other alloys will be used as well. In the aluminum alloys the variety may be even greater, but in practically all cases alloys 2S, 3S, 17S, 24S, and 52S will be available in the O and T states, at least.

In addition, many shops stock the various strong aluminum alloys in Alclad, which still further complicates the stock-room problem. If anodizing is done before storage, many of the sheets will have this finish, making the problem even more difficult.

Good stock-room practice is, accordingly, essential to any airplane sheet-metal shop. The various materials must be marked in an unmistakable manner to insure that they can be readily identified up to the final inclusion into the airplane assembly. Some of the materials come from the mill properly marked as to the alloy.

The proper marking of materials is an important function in the repair shop. Sometimes a color code is used. One that has served a good purpose is shown in Table I.

Owing to the growing use of mercury-arc lighting, the value of a color code has been considerably reduced since this lighting does not reveal the true color. A color code is not entirely satisfactory in connection with the aluminum alloys because the material variations are so great as to preclude the use of a moderate number of colors. In Table I only nine variations are possible which do not even half cover the possible materials and states that will be found in the aluminum-alloy stock of a well-equipped repair station. It has accordingly become the regular practice of most repair stations to use the color code only for the ferrous materials and to stamp the aluminum alloys with rubber stamps, using opaque metal ink, a material that is used by can makers and canners for code marking of their products. The rubber letters used are about ½ in. high and are made up like removable type so that a stamp giving any particular information desired can be made up quite readily. It is the usual practice to include on this stamp the thickness of sheet in thousandths of an inch. A typical stamp is as follows:

24SRT
049ALCD

This stamp indicates the material, and its heat-treated state, its thickness, and that it is protected with an aluminum covering known as Alclad.

TABLE I.—MARKING OF MATERIALS

Ferrous materials	Color	Aluminum materials
1020.........	Blue	2SO
1025.........	Red	2S¼H
2330.........	Yellow	3SO
4130.........	Dark green	3S¼H
2340.........	Nile green	4SO
Body steel...	Orange	17SO
2320.........	Ecru	17ST
Drill rod.....	Dark brown	24SRT
Stainless steel	Black	24ST

In marking steel, a small brush and a quick-drying lacquer are used. The thickness of steel sheet is marked on in thousandths of an inch. Bars are usually marked by an irregular stripe down their full length.

Sheet material, whether aluminum or ferrous, will be marked with a spacing of not over 4 or 5 in. in between any set of marks so that even relatively small pieces will still hold the identifying color or mark.

Glass jars are an excellent stock-room receptacle for various sizes and kinds of rivets in the ordinary repair shop where only a moderate quantity of supplies are necessary.

14. Welding-room Equipment.—If extensive welding is done and fabric-covered airplanes are worked on, the welding should be done in a separate compartment which must be adequately large to take the largest assembly that is likely to be repaired.

It is excellent practice to close off a fairly large compartment in which all metal work will be done, including welding, sheet-metal work, and riveting. This room will also contain the heat-treating apparatus for rivets and the strong aluminum alloys.

At least one acetylene torch with tips of sizes 1 to 7, inclusive, should be on hand. *If only one torch is available the outfit should be made up as a portable unit with tanks of oxygen and acetylene, with their proper regulators, mounted on a hand truck.* This will allow the welding unit to be moved to the job.

The torch used should be preferably of a type using a very low oxygen pressure—not above 2 or 3 lb. per square inch gauge. This is important in the repair shop, for torches that require a high oxygen pressure throw a very long flame, which is much more difficult to control, particularly in repair work on the assembled airplane or major components. A good part of the repairs can be done by electrical welding, having a motor-generator set as the source of power.

In any case, adequate preparations for fire protection must always be taken, guarding all parts with wet asbestos when an assembly having fabric covering is being welded. In addition, an assistant should stand by with a quick-acting fire extinguisher, preferably of the carbon dioxide type, as well as one of a soda acid type, so that any tendency to flame can be immediately stopped. Carbon tetrachloride fire extinguishers have their uses but they are not always as effective for this work as the carbon dioxide type.

The welding shop should be equipped with bench vises, an emery wheel, a portable buffer, and the usual hand tools, including micrometers of a type suitable for measuring the thickness of tubing. When tubular assemblies are made, it is necessary to apply protective coatings on the interior after completion. This is best done with a small tank to which 10 or 15 lb. of air pressure can be applied, forcing the lionoil or other protective material into the inside of the tubes. For sheet-metal work the shop must be properly equipped to use the various materials ordinarily found in airplanes. This will include not only the forming tools but also heat-treating facilities.

Review Questions

1. Name the classes of work for which a repair station may be approved.
2. Describe the equipment for an assembly hangar.

3. What safety precautions must be taken in dope rooms?
4. Describe the heat-treating equipment for a repair station.
5. Name the equipment usually found in a sheet-metal shop.
6. What tool is used for layout work on aluminum-alloy sheets?
7. Describe the care of vises in a sheet-metal shop.
8. Name two precautions in sawing sheet metal on a band saw.
9. Describe a nibbling machine.
10. How are metals, in a stock room, marked and segregated?

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2. Civil Air Regulations Governing Alteration and Repair of Certificated Aircraft.

3. "Stanley Tool Catalogue," The Stanley Rule and Level Plant, The Stanley Works, New Britain, Conn.

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7. COLVIN, F. H., and F. A. STANLEY, "American Machinists' Handbook," McGraw-Hill Book Company, Inc., New York.

8. "Hack Saws and Their Uses," The L. S. Starrett Co., Athol, Mass.

9. "A Handbook of Portable Electric Drill Practice," United States Electrical Tool Co., Cincinnati, Ohio.

10. "Brown & Sharpe Small Tools," Brown & Sharpe Manufacturing Co., Providence, R. I.

Questions for Thought and Study of References

1. Describe the use and care of a hack saw. (Ref. 8.)

2. Name 20 kinds of files and describe each. Describe the use of files in aircraft sheet-metal work. (Ref. 1.)

3. How would you sharpen a drill? (Refs. 5 and 9.)
4. Explain how to determine speed and feed in drilling with a power drill.
5. Explain the principle on which a level operates.
6. How do you clean files?
7. What is a trammel?
8. Explain how to use a micrometer. (Ref. 5.)
9. Name the kinds of calipers and explain how they are used.
10. Name the parts of a cold chisel.
11. How are reamers used?

CHAPTER III

AIRPLANE PARTS AND EQUIPMENT: STRUCTURAL TYPES AND NOMENCLATURE

The purpose of this chapter is to familiarize the student with modern airplanes, their parts and the function of the parts, their equipment, their structural types, and the nomenclature involved.[1]

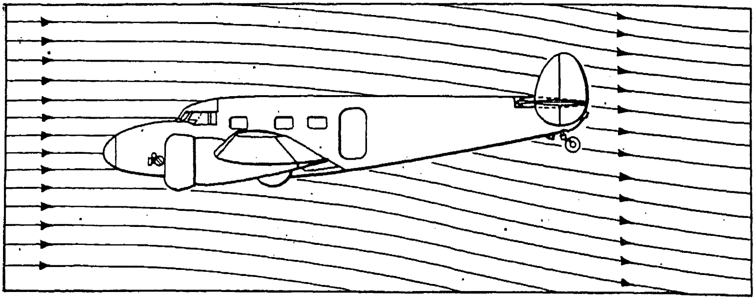

FIG. 3.—Air forced downward by wings of airplane to sustain flight.

15. Airplane Types.—Figures 5 to 11, inclusive, show the typical types of airplanes now in general use. To avoid the use of additional figures, the nomenclature is included in these figures.

16. Fundamental Parts.—The fundamental parts of an airplane are: *wings*, *fuselage*, *controls* and *control surfaces*, *landing gear*, *power plants*, and *propellers*. Aside from these parts there are many auxiliary parts required to fit the airplane for modern transportation usage.

17. Wings.—Wings sustain the airplane in flight by the reaction caused in forcing the surrounding air, passed through, downward (see Fig. 3). The principle involved is that of *impulse* and *momentum*. Impulse is the force necessary to give a mass momentum. The upward impulse on the wings, causing the downward momentum of the air, lifts the airplane.

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[1] For additional nomenclature see figures of Chap. IX. The student should also have Ref. 5, Nomenclature.

Airplane wings are designed to give a maximum of lift for a minimum of propeller thrust. The latter implies, also, for a minimum of power. This explains the reason for the cambered (curved) surfaces of airfoils. Air passes over these surfaces with a minimum of turbulence, thus conserving the energy of the motors, because turbulence is a great energy absorber.

The amount of lift depends upon and is proportional to:

1. *The area of the wing;* that is, the mean chord times the span (see Fig. 5).
2. *The square of the speed;* for example, if all other conditions remain the same, to double the speed increases the lift four times.
3. *The air density;* for example, at 20,000 ft. altitude, where the air density is only about half that at sea level (other conditions remaining the same), the wings will lift only half as much.

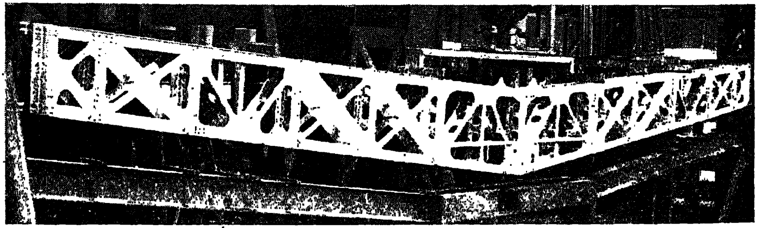


FIG. 4.—Cantilever wing spar of Lockheed Electra, center section; aluminum-alloy, thin-sheet-metal, riveted construction.

NOTE: The drag, however, at 20,000 ft. altitude is only half as great so that a greater speed may be attained for the same power.

4. *The angle of attack* of the wing. Tests are made on models of wings to determine this effect. The results are tabulated with lift and drag coefficients as a function of angle of attack. See elementary books on aerodynamics.

Wing structures are designed to sustain a load of 4 to 10 (called load factors) times the weight of the airplane (see CAR Part 14).

18. Monoplane.—Monoplanes may be classified as:

1. *Braced;* that is, the wing structure is braced externally (see Fig. 9).
2. *Cantilever* (see Figs. 5, 7, 8, 10, and 11), that is, the wing structure is braced internally, with no external bracing. The wing itself may be the cantilever beam, or the wing may be built over one, two, or more cantilever beams.

Monoplanes may also be classified as:

1. *High-wing.*—The wing is above the fuselage, either cantilever or braced (see Figs. 9 to 11).

2. *Low-wing.*—The wing is below the fuselage, either cantilever or braced (see Figs. 5, 7, 8).

3. *Mid-wing.*—Figure 4 shows a cantilever wing spar. The wing passes through the center of the fuselage.

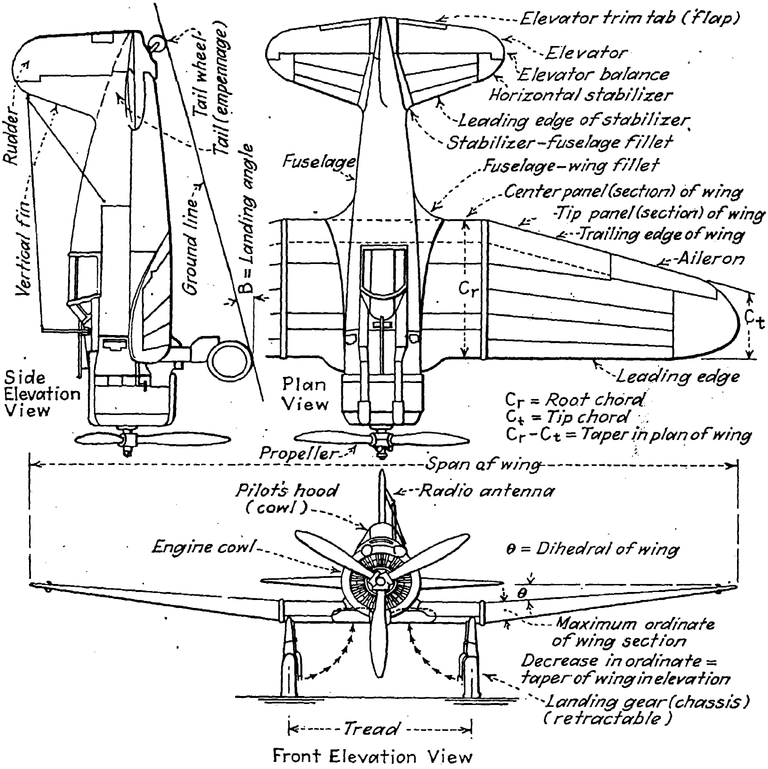


FIG. 5.—Parts of an all-metal low-wing monoplane. Cantilever wings. Retractable chassis. Structure, semi-monocoque. (Vought V-143.)

19. Biplane.—Biplanes have two wings—one above the fuselage, and one below the fuselage (see Fig. 6). The bracing consists of struts, flying wires, landing wires, etc.

20. Material of Wings.—Cantilever monoplanes are, with practically no exceptions, built of metal because of the rigidity required for high-speed flight. Braced monoplanes and biplanes are generally built of wood, wire, and fabric, though many have metal spars and ribs, and metal tubular fuselages.

21. Wing Ribs and Spars.—Ribs transmit the air load from the covers to the wing beams (spars) (see Fig. 6). The wing beams

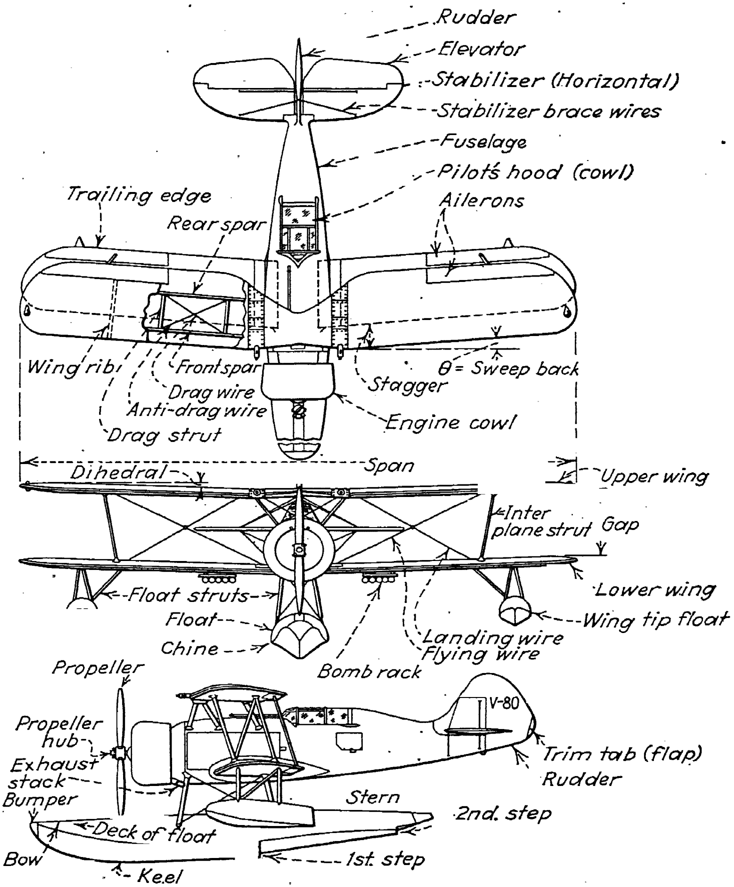


FIG. 6.—Three-view drawing of single-motored biplane seaplane showing typical parts. (Vought "Corsair" V-80.)

transmit the load to the fuselage. Another viewpoint is: The fuselage is supported by the wing spars, while the spars are supported by the ribs, and the ribs are supported by the wing skin.

If any part of an airplane can be said to be more important than any other part, *the spars are the most important structural part of an airplane*, since they are the main supporting members. Cantilever spars (Fig. 4) are quite massive and heavy in structure, in comparison to other structural parts. All parts of such a spar carry excessively high loads, which must be taken into consideration in making repairs.

22. Fuselage.—The fuselage is the body of the airplane. See Fig. 12 for structure and nomenclature. The fuselage houses the passengers, crew, cargo, instruments, etc. (see Fig. 7). Parts which require the attention of a mechanic are:

1. *In the passenger cabin*—seats and upholstering, floors, windows, soundproofing, heating and ventilation, buffet, lavatory, and toilet, emergency exits, and finish of all parts.
2. *Cargo compartments and mail and baggage compartment.*
3. In the *crew compartment*—*instruments*, *controls*, *fire-fighting equipment*, *navigation equipment*, *windows*, *doors*, finish of all parts, *radio* and *radio accessories*.

23. Controls and Control Surfaces.—Control surfaces develop the required forces to control the airplane by increasing or decreasing the effective angle of attack of the surface of which they are a part (see Fig. 13). The controls are:

1. *Rudders.*—These control the airplane (in yaw) about an imaginary vertical line (called the vertical axis) through the center of gravity of the airplane, the airplane being in the flying position. The rudder is controlled by the pilot's feet. Pushing on the left foot *yaws* the airplane to the left; pushing on the right foot *yaws* it to the right.
2. *Elevators.*—These control the airplane (in climbs, glide, or dive) about an imaginary horizontal line parallel to the wing beams (called a transverse axis) and passing through the center of the gravity of the airplane. The elevators are controlled by pushing the control column forward for a dive, and pulling it backward for a climb.
3. *Ailerons.*—These control the airplane (in roll) about an axis parallel to the propeller shaft (the longitudinal axis) and passing through the center of gravity of the airplane.. The ailerons are controlled by the rotation of the handwheel on the control column. The airplane rolls in the same direction the wheel is turned. Small airplanes do not have wheel aileron controls. The control column (called the "stick") is moved to the left or right. The roll of the airplane follows the direction of motion of the "stick." See Fig. 14 for additional nomenclature.
4. *Control Wires.*—In general, motion from the control column is transmitted to the control surfaces by means of special control wires operating over ball-bearing pulleys. Push and pull rods (made of light tubing) are sometimes used.

5. *Vertical fins and horizontal stabilizers* serve to stabilize the airplane in its flight path, somewhat like the feathers on an arrow serve to guide the arrow in its flight. The rudder is hinged to the fin, and the elevators are hinged to the horizontal stabilizer.

6. *Wing flaps* are used to slow the airplane down for landing (see Fig. 15). For the same speed of the airplane, the flaps increase the lift of the wings about one third or more, enabling the airplane to fly with a much lower speed while landing. The flaps are controlled by handwheels or levers in the pilot's compartment.

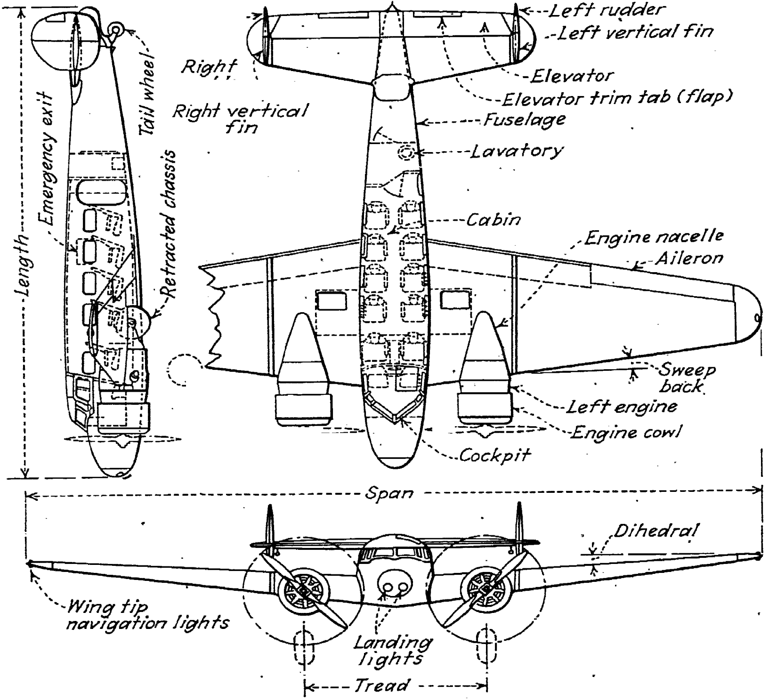


Fig. 7.—All-metal low-wing, bi-motored, high-speed transport monoplane. (Lockheed Electra.)

7. *Balanced Control Surfaces.*—The control surfaces may be balanced aerodynamically to lessen the effort required by the pilot in their operation. This is accomplished by the addition of a part of the surface forward of the axis of the hinges. The control surfaces may also be statically balanced to prevent fluttering.

8. *Trimming Tabs or Flaps.*—These are small flaps set in the trailing edge of a rudder, an elevator, or an aileron, and controlled by independent means. Their purpose is to trim the airplane so that it is perfectly balanced in flight. In this state, the airplane will fly "hands off" the controls.

24. Landing Gear (Chassis and Tail Wheels).—Landing gears are generally retractable. See Fig. 17. Features which require a mechanic's attention are:

1. Wheels and axles.
2. Tires.
3. Brakes and brake mechanism.
4. Shock absorbers.
5. Brace struts and trusses.
6. Retracting strut, screw, or gear.
7. Safety latch.
8. Indicating mechanism.
9. Retracting mechanism.
10. Lubrication.

For water craft, pontoons, boats, or floats take the place of landing gears (see Figs. 6, 10, and 11).

25. Hydraulic (Oil) System.—This system is generally used for the operation of retractable landing gears and tail wheels, operation of brakes, wing flaps, etc. Diagrams of the hydraulic systems are furnished repair shops by the manufacturer.

26. Automatic Pilot.—General description and instructions (Maintenance Manual of Douglas Model DC3-178):

The Sperry automatic pilot provides control of rudder, ailerons, and elevators; maintaining directional, lateral, and longitudinal stability required of an airplane in flight. It consists of the following major units; namely, *gyro controls, mounting, hydraulic servo, speed-control valves, oil-pressure-relief valve, and vacuum pumps.* The gyros similar to the Sperry directional gyro and horizon are used to provide data lines from which the control surfaces are hydraulically operated. These gyros are air-driven by vacuum supplied by a Pesco vacuum pump mounted on the angular drive of each engine. A vacuum of from 4 to 5 in. of mercury is required. The controls may be operated by oil pressure supplied by either the right or left engine oil pump (Pesco high-pressure type operated by engine accessory drive) as selected by valve on hydraulic panel. Oil pressure of about 100 lb. is required.

The gyro control units consist essentially of the horizon and directional gyros. It is not intended that the repair or adjustment of the control units be attempted anywhere outside the Sperry factory or by any other than an authorized Sperry repre-

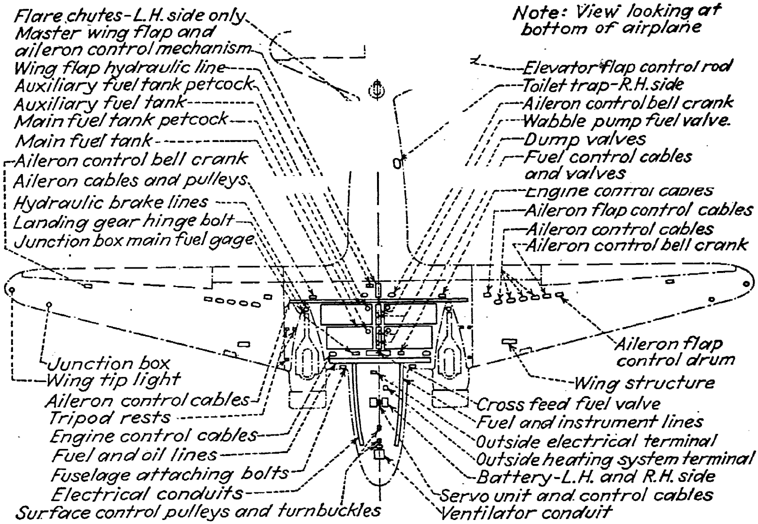

Flare chutes-L.H. side only
Master wing flap and aileron control mechanism
Wing flap hydraulic line
Auxiliary fuel tank petcock
Auxiliary fuel tank
Main fuel tank petcock
Main fuel tank
Aileron control bell crank
Aileron cables and pulleys
Hydraulic brake lines
Landing gear hinge bolt
Junction box main fuel gage
Junction box
Wing tip light
Aileron control cables
Tripod rests
Engine control cables
Fuel and oil lines
Fuselage attaching bolts
Electrical conduits
Surface control pulleys and turnbuckles
Note: View looking at bottom of airplane
Elevator flap control rod
Toilet trap-R.H. side
Aileron control bell crank
Wabble pump fuel valve.
Dump valves
Fuel control cables and valves
Engine control cables
Aileron flap control cables
Aileron control cables
Aileron control bell crank
Aileron flap control drum
Wing structure
Cross feed fuel valve
Fuel and instrument lines
Outside electrical terminal
Outside heating system terminal
Battery-L.H. and R.H. side
Servo unit and control cables
Ventilator conduit

FIG. 8.—Bi-motored all-metal low-wing monoplane transport. Diagram of inspection doors and cover plates. (Douglas Model DC3-178.)

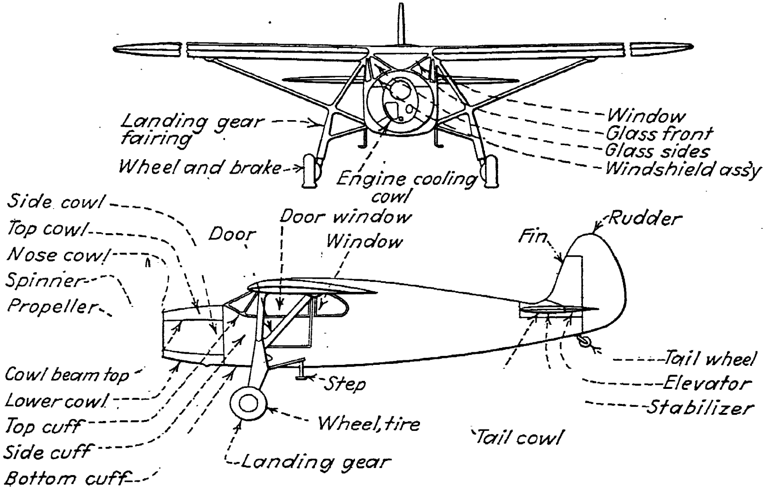


FIG. 9.—High-wing, cabin, braced-wing monoplane. Typical design for private owner. Structure: fuselage, welded-steel tubing; wings, wood, wire-braced; doped fabric covering. (Fairchild 24, M-C-8E.)

sentative. If any trouble is traced to the control units, the Sperry Gyroscope Co., Inc., should be notified.

27. Power Plant.—The power plant, of course, provides power for flight. Repair of the engines is out of the scope of an airplane mechanic's job. However, the removal and installation of engines will require his assistance.

The power plant also provides power for auxiliaries; such as light, motors for operating landing gears, flaps, etc. As airplanes increase in size, auxiliary motors will be required to supply this extra power. This will be especially true when airplane cabins and engines are supercharged to fly in the substratosphere (25,000 to 30,000 ft. high).

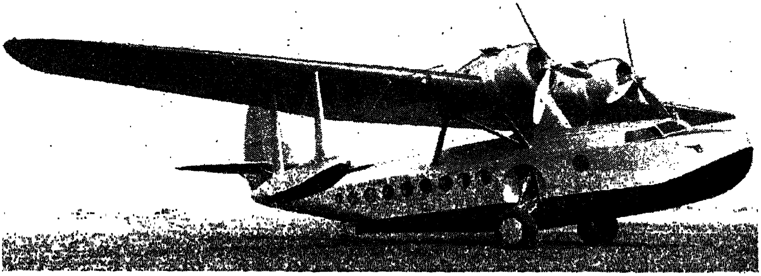


FIG. 10.—Amphibian, Sikorsky S.43.

28. Propellers.—Propellers actuated by the engines provide the thrust for flight. Each elementary section along the radius of the propeller is an *airfoil* which operates to provide thrust just as a wing operates to provide *lift*. The element travels in a circle as it moves forward as though it were sliding along the thread of a machine screw. The *angle of attack* of the element depends upon the relation of the forward velocity of the airplane to the angular velocity of the propeller. Thus a propeller, with a fixed blade setting, which operates efficiently at a low speed (at take-off, for example) will not operate efficiently at a high speed. To remedy this a *controllable-pitch propeller* was devised, the blades of which could be set at one angle for take-off, and at a greater angle for high speed.

NOTE: *Controllable pitch* is used to indicate control in flight, while *adjustable pitch* is used to indicate propellers, the blade angle of which may be set in the shop, but is fixed in flight.

Constant-speed propellers automatically control the pitch of the propeller blades so that the speed of rotation remains constant.

29. Fuel System.—The fuel system of a large transport airplane is quite a complicated affair, as the following outline will show. A fuel system consists of:

1. *Lines from the several tanks* which concentrate at a *tank selector valve.*
2. From the tank-selector valve the single main line usually runs through a *strainer*, and *wobble pump* to the engine selector valve.
3. From the engine-selector valve, a line runs to each engine, passing through a *fuel pump* and *carburetor.*
4. Each fuel tank has a *gauge* in the pilot's compartment. The tanks are provided with *sumps* and *drain cocks*, and generally *dump valves.*

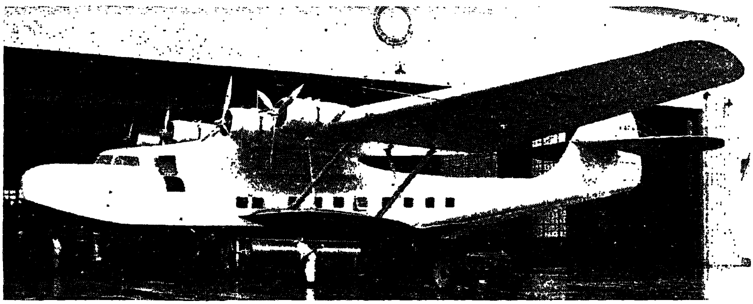


Fig. 11.—Flying boat (hydroplane), Martin model 130. (China Clipper.)

5. *Cross-feed lines* are provided in case of failure of a part of the system. This requires additional lines and valves.
6. *Engine primers* are provided for *starting motors.*
7. The fuel pressure to the engine is indicated on the instrument board. (See Appendix for inspection procedure.)

30. Oil System.—The oil system has for maintenance:

1. Piping system.
2. Tanks.
3. Coolers.
4. Pressure and temperature regulation.
5. Drainage.

31. Engine and Aeronautical Instruments.—These include:

1. Instrument board.
2. Flight panel.
3. Oil- and fuel-pressure panel.
4. Magnetic compass, etc.

32. Electrical Installation.—This includes:

1. Electrical control panel.
2. Ignition-system panel.
3. Starters and generator system.
4. Fuses.
5. Exterior lights.
6. Interior lights.
7. Landing-gear warnings.
8. Electrical instruments.
9. Batteries.
10. Junction boxes.

A wiring diagram is usually furnished in manuals of instruction for airplanes.

33. Radio Equipment.—This equipment comes under the jurisdiction of the radio mechanic, though the airplane mechanic will be required to render assistance in *removals* and *installations.*

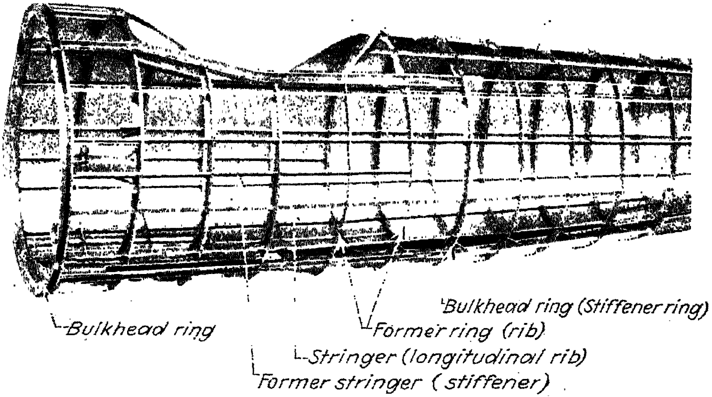

Bulkhead ring (Stiffener ring)
Bulkhead ring
Former ring (rib)
Stringer (longitudinal rib)
Former stringer (stiffener)

FIG. 12.—Bracing structure of a semi-monocoque fuselage.

Radio requires special shielding of certain electric lines in metal tubing, and special bonding of all metal parts of the airplane.

34. Heating and Ventilating System.—Transport airplanes are equipped with rather elaborate heating and ventilating systems. The future will require complete air-conditioning systems.

Figure 19 shows a heating and ventilating system which illustrates the principal features.

The operating principle of the system is as follows:

The *boiler* operates as a *dry boiler,* admitting water only when there is a demand for steam in the radiator. Under normal operation the *radiator* is always full of steam, the *reserve water tank* adding water as needed to keep the boiler and radiator full of steam. As the steam gives up its heat to the air flowing through the radiator, it condenses and flows back to the boiler. Connected to a tee, where the water return line ties into the radiator, is a line which runs to a *regulating valve* on the top of the water tank. This line removes air from the radiator coils and supplies steam above the water.

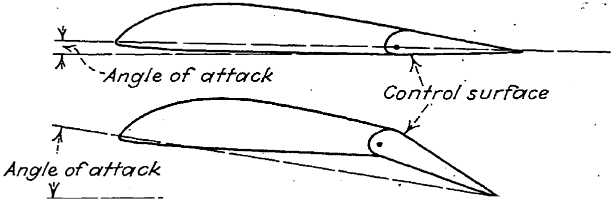


FIG. 13.—Effective angle of attack increased by angular displacement of control surface.

It is within the province of the airplane mechanic's job to maintain such a system.

35. Soundproofing.—All transport airplanes are soundproofed and vibration-proofed. As a description of a modern example we quote from the Maintenance Manual of the Douglas DC3-178:

> The soundproofing is accomplished in three ways: by eliminating or minimizing noises at their source; by building doors, panels, etc., in such a way that they will not transmit sounds; and by reducing the remaining sound level with special absorptive materials. Large, flat surfaces such as walls and partitions are stiffened or shock-mounted, wherever possible, to eliminate their tendency to "drum." Special draft felts are used in the forward cabin wall and the rear lavatory wall. The felts effectively seal the holes where the fuselage longitudinals pass through the frames. Floor supports are shock-mounted, and the floors themselves are mounted in rubber, giving a waterproof installation. Shock and rubber mountings are provided for the partitions separating the passenger compartments. The heavy cabin carpet serves to absorb considerable sound.
>
> Materials used and their manufacturers are as follows:
>
> 1. Seapak and Kapok Felt: Seaman Paper Co., Chicago, Ill.
> 2. Akoustikos Felt: Johns-Manville Co., New York, N. Y.
> 3. Paratex: Blockson Co., Los Angeles, Calif.

4. Sponge rubber Waterproofing Strip, ¼ and ½ Inch: Kansas City Trimming Co., Kansas City, Mo.

5. Plastikon Rubber Cement: Goodrich Rubber Co., Akron, Ohio.

6. Vultex Cement: Vultex Chemical Co., Cambridge, Mass.

To maintain best sound control:

1. *Periodically inspect* all cabin fixtures, seats, and furnishings for looseness of attachments and fittings. Any small constant rattle or noise will add to the sound level and annoy the passengers.

2. *Replace door strips* at first signs of deterioration. Small cracks in the stripping will allow a large percentage of outside noise to enter the cabin. Inspection in flight will often reveal faulty stripping which cannot be detected on the ground.

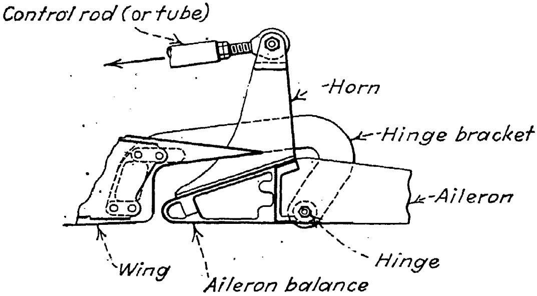


FIG. 14.—Aileron parts.

36. Miscellaneous Equipment.—Under this heading may be listed the following:

1. Fire-fighting equipment (see Fig. 20).
2. Flares.
3. Control-surface locks.
4. Engine covers.
5. Chart boards.
6. Tables for passengers.
7. Serving trays.

37. De-icers.—These items of special equipment are becoming more and more important as service becomes more regular, and as service altitudes are increased.

The de-icing system of the Douglas DC3-178 is as follows:

1. *Carburetor de-icing* is accomplished by pumping alcohol into the throat of the carburetor just above the venturi opening. Two Auto Pulse pumps, one supplying each carburetor, are located on the wall back of the pilot and

pump alcohol from the supply tank to the carburetors. The control switch for the Auto Pulse pumps is located on the upper left electrical panel, forward and above the pilot. The alcohol tank of 3-gal. maximum capacity is located over the cargo-loading door and is filled from the inside. A valve near each pump, located on the wall just inside the pilots' door, regulates the flow into the carburetor.

2. *Windshield de-icing* is effected by pumping alcohol from the supply tank into small lines filled with holes which encircle and spray the outside of the front outboard and the sliding side windows. Pumping is accomplished by the use of a small hand pump bracketed below the right window where the copilot may operate it. The pump supplies both right and left windows, and a valve just below each sliding window regulates the flow of alcohol in the lines.

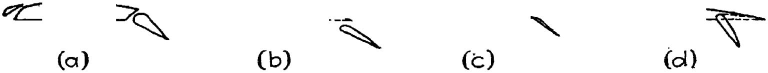


FIG. 15.—Typical wing flaps. (*a*) Handley page slot and flap; (*b*) Fowler variable wing area; (*c*) zap flap; (*d*) split flap.

3. Piping for an alcohol or *alcohol-glycerin propeller slinger de-icer* is installed from the pilots' compartment to the nacelle fire walls.

Figure 21 shows a mechanical de-icer for the *leading edge* of wings.

The mechanical de-icer is composed of several parts, namely, the air pump, the oil filter with relief valve, the distributing valve, and the rubber overshoes.

The design of the pneumatic overshoe consists essentially of several layers of rubber and fabric which form tubular air cells. These cells with their covering are fitted to the surface of the airfoil so that the tubular cells are parallel to the surfaces to be protected. The number of the longitudinal parallel cells in each surface covering depends on the form and area to be protected. The removal of the ice formation is accomplished by periodically inflating and deflating the tubular cells, progressively, not simultaneously. The constant movement of the surface coverings and the stretch of the rubber breaks the ice as it is formed and it is carried away by the air stream. In this manner the formation of ice is checked. These overshoes were designed by the B. F. Goodrich Rubber Company.

JOB UNITS

Job Unit 1. Study of Airplane Structural Types by Observation

Object: To study the modern structural types of airplanes.

Method: By visiting an airport and studying structural types of airplanes by observation.

In preparation for a class visit to an airport, the instructor should obtain permission in advance for his class to enter each of the hangars and inspect the airplanes therein. Generally an assistant will be detailed to conduct the class around and answer any questions the students may ask. Each student should provide himself with a notebook having a stiff cardboard back for use in making sketches while standing.

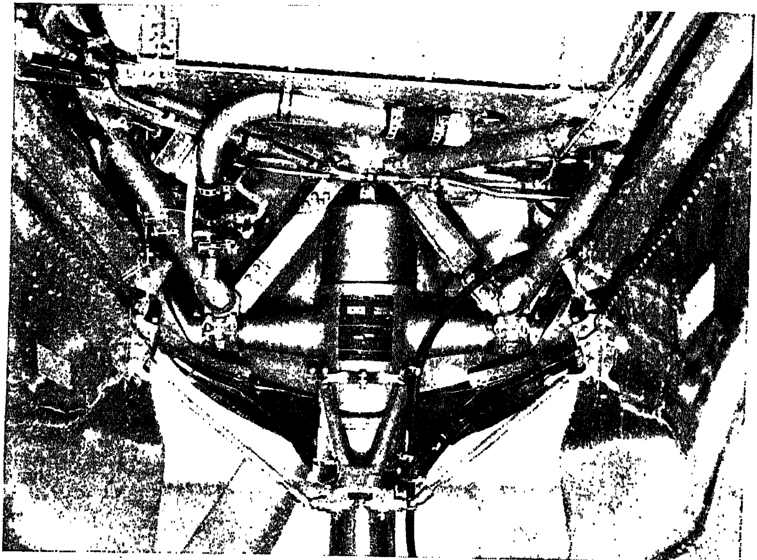


FIG. 16.—Landing-gear-retracting mechanism and oil lines on wheel well on Martin 167. (*Courtesy of The Glenn L. Martin Company.*)

For each airplane studied the student should make an outline as follows:

1. Name of airplane.
2. Name and address of manufacturer.
3. Horsepower, approximate weight.
4. Span, length and chord, wing area.
5. Passenger, freight, mail, sport plane, etc.
6. Biplane, monoplane, etc. Low wing or high wing. Draw front-view and side-view sketches.
7. Type of structure of wings.
8. Type of structure of fuselage.
9. Type of landing gear and shock absorber.
10. Other information of interest and value to a mechanic. Jot down the answers to questions which may be of use later in the work.

11. Make a report for the trip, arranged in a neat form, to the instructor within two or three days after the trip. In connection with each airplane or group of airplanes of a certain structural type, include a summary of the information a mechanic must possess to make any repair on the structure.

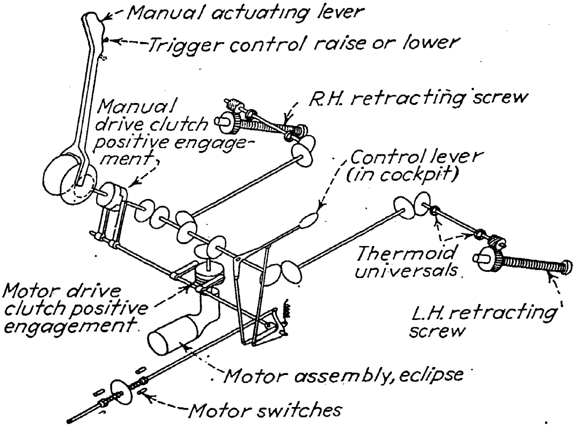
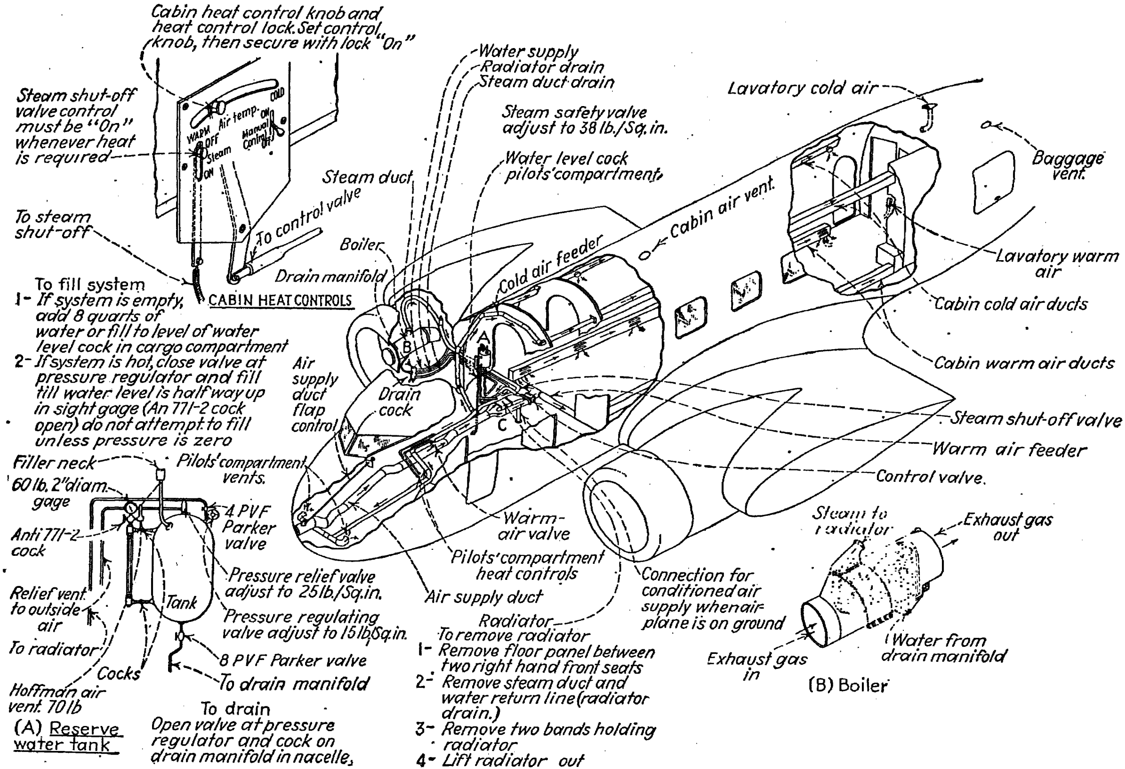

Manual actuating lever
Trigger control raise or lower
Manual drive clutch positive engagement
R.H. retracting screw
Control lever (in cockpit)
Thermoid universals
Motor drive clutch positive engagement
L.H. retracting screw
Motor assembly, eclipse
Motor switches

FIG. 17.—Example of landing-gear retracting mechanism. (Boeing 247.) The retracting mechanism is shown diagrammatically and consists essentially of the following units: A reversible-action, double-acting ratchet-type actuating handle on right side of pilot's cockpit; positive-type engaging clutches with actuating lever located on control stand in pilot's cockpit; and a series of torque tubes carried in ball-bearing gears for driving the retracting screws. (*Courtesy of Boeing Airplane Company.*)

FIG. 18.—The B-17 (Flying Fortress).



To fill system
1- If system is empty, add 8 quarts of water or fill to level of water level cock in cargo compartment
2- If system is hot, close valve at pressure regulator and fill till water level is half way up in sight gage (An 771-2 cock open) do not attempt to fill unless pressure is zero

To drain
Open valve at pressure regulator and cock on drain manifold in nacelle.

To remove radiator
1- Remove floor panel between two right hand front seats
2- Remove steam duct and water return line (radiator drain.)
3- Remove two bands holding radiator
4- Lift radiator out

FIG. 19.—Heating and ventilating system of an airliner. Water is flashed into steam in boiler *B* by heat of exhaust gas. The steam passes to radiator *C*, where it heats ventilating air. (Douglas model DC3-178.)

Job Unit 2. Library Study of Structural Types of Airplanes

Object: To study modern structural types of airplanes.

Method: By the use of library references, such as periodicals and books.

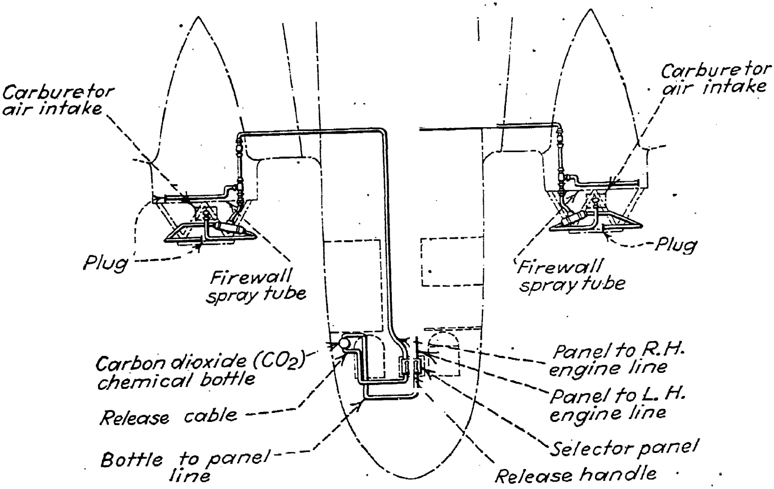


FIG. 20.—Diagram of a fire-fighting system on a bi-motored transport. (Douglas DC3-178.)

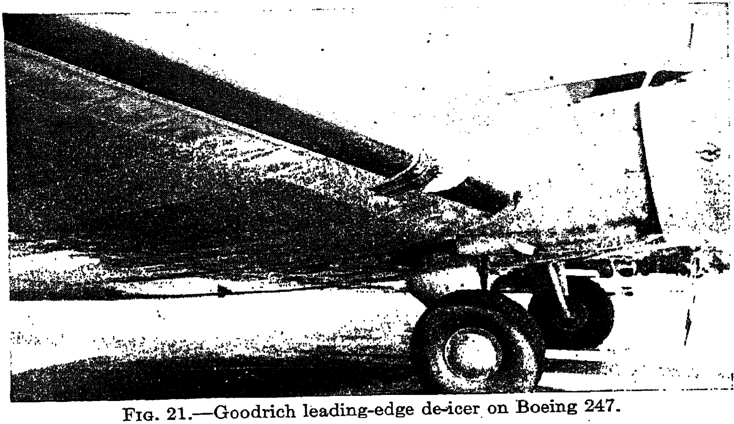


FIG. 21.—Goodrich leading-edge de-icer on Boeing 247.

When a new-model airplane is placed before the public, aeronautical periodicals carry photographs and descriptions of its characteristics. The best information on existing airplanes may be obtained, therefore, by reference to these periodicals.

1. The instructor may have some one look through copies of available aeronautical periodicals not more than one year old and make a list of articles on new-type airplanes. The name of the periodical and date of the issue should be listed.

2. Assign one student to each article for careful study of the article.

3. The student should select important structural details of interest to mechanics and prepare these details for a report to his class.

4. About 5 to 10 min., if the size of the class will allow, of the class period should be allowed each student to make his report and answer questions propounded by other students. Discussions of the merits of different types of construction should be encouraged.

Review Questions

1. Name the fundamental parts of an airplane. State the function of each part.

2. Name seven structural types of airplanes.

3. How do wings develop lift?

4. How does a propeller develop thrust?

5. How is a propeller section similar to a wing section?

6. Name the control surfaces, state how each is operated, and explain the aerodynamic theory of operation.

7. What is the purpose of a wing flap?

8. How do the trimming flaps operate?

9. Name the usual instruments of an airplane cockpit.

10. Explain the methods of soundproofing a cabin.

References

1. CHATFIELD, C. H., C. F. TAYLOR, and S. OBER, "The Airplane and Its Engine," McGraw-Hill Book Company, Inc., New York, 1940.

2. "Janes All the World's Aircraft," Sampson Low, Marston and Company, London.

3. "The Aircraft Year Book," Aeronautical Chamber of Commerce of America, Inc., New York.

4. JONES, B., "Elements of Practical Aerodynamics," John Wiley & Sons, Inc., New York, 1939.

5. Nomenclature for Aeronautics, *Report* 240, National Advisory Committee for Aeronautics, Washington, D. C.

6. Annually, the periodicals *Aero Digest*, *Aviation*, and *Western Flying* bring out issues that catalogue thoroughly current airplanes (except new military).

Questions for Thought and Study of References

1. Name the two principal requirements for an airplane structure.

2. What is meant by a "clean" design?

3. State the chief advantages of (*a*) a high-wing monoplane; (*b*) a low-wing monoplane.

4. Why are thick wing sections used for cantilever monoplane wings?

5. What is a tractor airplane?

6. List the relative advantages and disadvantages of biplanes and monoplanes.

7. Define "streamlined section."

8. Define parasite drag, yaw, dihedral incidence, angle of attack, three-point landing, aerodynamic efficiency, and structural efficiency.

9. What is wing flutter? Aileron flutter?

10. What is "buffeting?"

CHAPTER IV

STATIC AND DYNAMIC TESTING

Testing an airplane structure for strength under stationary conditions is called *static testing,* and under moving conditions, *dynamic testing.* The importance of the study of structural testing may be listed as follows:

1. *In no other mode of transportation is the strength of the structure of the vehicle so important as in the airplane.* One of the first jobs of the mechanic, as a student, is to learn to appreciate this fact. It should become a kind of "second nature" with him to consider the structure of the airplane in terms of the many types of loads it must carry. No other form of instruction will give the student a fuller appreciation of the requirements of the structure than static and dynamic testing.
2. *Frequently it becomes desirable to alter a part of an airplane structure;* for example, a control surface, a part of a landing gear, or a part of the fuselage, for a special purpose. These are design problems and as such are governed by CAR Part 04. (See Structural Tests.) The change may be allowed, provided the structure is tested in the specified manner in the presence of an inspector.
3. *Testing of students' repair work* in the laboratory teaches an appreciation for the fundamental requirements. Let the student see for himself why his work is good or bad.

38. Scope of Tests.—The ideal, in testing, is to simulate, as nearly as possible, the actual loading conditions required for the part of the structure to be tested. The loading requirements specified by the Civil Aëronautics Administration, the Army Air Forces, or the Navy, were determined by numerous experiments, and after many years of experience. Specifications may be found for the following tests (the load in each case is specified):

1. Controls and control wires.
2. Center of gravity and balance tests.
3. Wing ribs.
4. Seats and their supporting structure.
5. Leading edge of wing.
6. Wing structure under various flying conditions.
7. Control surfaces.
8. Landing gear and tail wheel.
9. Fuselage.

39. Principles Involved.—These may be listed as follows:

1. *Simple proportion* is required for dividing the load into the proper proportion on the surface to be tested.

2. *The load, in the static tests, should be applied very slowly as impacts in applying the load may cause the structure to fail prematurely.* The usual procedure is to support the structure and the load by several jacks while the load is being applied. The jacks are then all lowered, simultaneously, quite slowly, until they are free.

3. *The test should be arranged so that in the case of a failure, the entire structure will not collapse* as it is desirable to note the first point of failure, which is the weakest point of the structure. It is the usual practice to lower the jacks so that they are barely clear of the structure.

4. *To obtain as much information on the strength of the structure as possible,* when the first failure occurs, the jacks should be raised to carry the load; the load should be removed, and the failure should be repaired ("beefed up"), so that it will not fail at that point again. This procedure may be followed for the first several failures.

40. Center of Gravity.—The importance of this study is as follows:

1. The loads, in static tests, are applied with reference to the center of gravity of the load.

2. The airplane must be properly balanced in the air. This means that the center of gravity of the airplane must be located quite near the center of lift of the wings. An unbalanced loading of an airplane is dangerous. Modern transport airplanes are loaded according to a definite balance schedule.

41. How to Find the Center of Gravity.—Two principles are conveniently used for finding the location of the center of gravity; they are:

1. The principle of the lever.

2. The assumption that the entire weight of the body is concentrated at the center of gravity of the body. This is equivalent to assuming that the structure has no weight, and the weight is a force applied at the center of gravity of the body.

For example, consider Fig. 22. We represent the weight of the airplane by the line W with an arrow representing the force acting downward. (This line representation of a force is called a vector.) We represent the loads on the scales by vectors W_1 and W_2. Then, by the principle of the lever, we have

$$W \times a = W_2 \times L$$

From this, $a = W_2L/W$. But $W = W_1 + W_2$, the total weight of the airplane. (The weight W_1 is the sum of the weights indicated by two scales, one under each landing-gear wheel.)

This line W is a vertical line passing through the center of gravity. It locates the longitudinal position but not the vertical

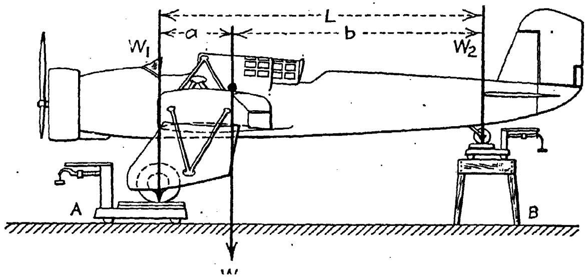


FIG. 22.—Finding the longitudinal location of the center of gravity of an airplane.

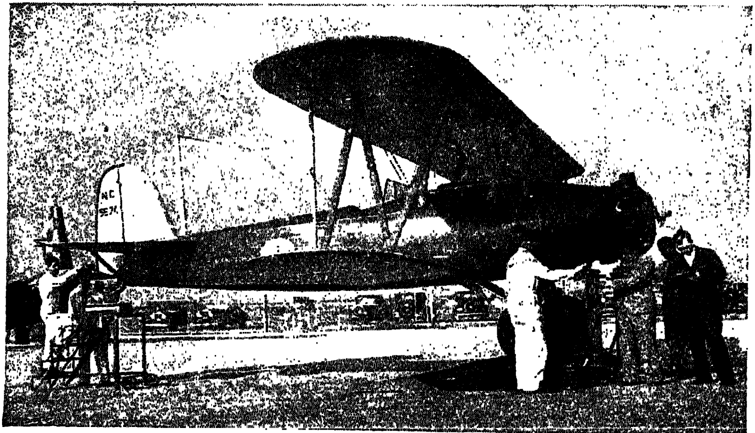


FIG. 23.—Weighing airplane with scales at three points to find its weight and center of gravity location. (*Courtesy of Boeing School of Aeronautics.*)

position of the center of gravity. However, if the airplane is nosed over, and the scale W_2 of Fig. 22 is placed under the nose, then the location of the vertical line through the center of gravity may be found by the application of the principle of the lever, as noted above. The intersection of this line with the previous line found will be the center of gravity of the airplane.

To locate the center of gravity in the airplane it will probably be necessary to lay out the distances *a* and *L* and the lines through the center of gravity on a side view of the airplane, drawn to a known scale (see Fig. 23).

42. Static Test of an Aileron.—Specifications for aileron static testing are given by the Army, the Navy, and the CAA. See Civil Air Regulations for tests on commercial airplanes. These regulations are changed frequently and are relatively complicated, making it impractical to present the details in a text. The students should obtain the specifications from the one of the three sources in which he is interested.

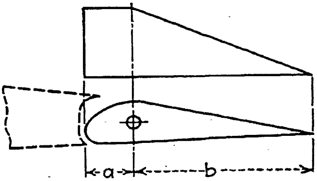


FIG. 24.—Aileron chord distribution.

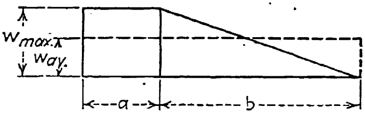


FIG. 25.—Relation between average load and maximum load.

The following example illustrates the fundamentals involved:

Assume the load is distributed as in Fig. 24 and that an average load of 12 lb. per square foot is specified.

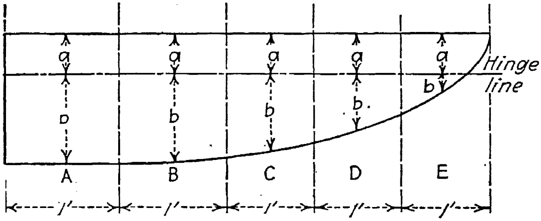


FIG. 26.—Marking of aileron for loading in static test.

Since the loading is specified in pounds per square foot, the diagram, Fig. 24, represents the loading for one foot width of the aileron; that is, one foot measured along the torque tube. With reference to Fig. 25, the total minimum loading for this foot width is, $w_{av}(a + b)$, in which w_{av} is the average loading per square foot (in this case specified as 12 lb.), *a* is the distance from the hinge to the leading edge, and *b* is the distance from the hinge to the trailing edge. Both *a* and *b* are in feet. Assume for this example, that *a* is 1 ft. and *b* is 2 ft., then the total load per foot on the aileron at this section is $12(1 + 2) = 36$ lb. This 36-lb. load must be distributed according to Fig. 24. It is necessary therefore that we find $w_{\max}$ (Fig. 25). It is found as follows:

The total loading is $w_{\max}[a + (b/2)]$. This, as we have noted is 36 pounds, thus $w_{\max} \times [1 + (2/2)] = 36$, or $w_{\max} = 18$ lb. per square foot. If the aileron chord is not uniform, this calculation must be made for each foot of the aileron, a and b being measured at the center of each foot of the aileron (see Fig. 26). For the test proceed as follows:

1. Support the aileron in a flying position by the hinges and control wires. It will be convenient to set the aileron in a jig provided for the purpose (see Fig. 27).
2. Mark off the aileron as in Fig. 26.
3. Lay out the sand or shot bags on the floor to correspond to the loading schedule of Fig. 26, the load to be forward of the hinge for each section A, B, C, etc., and the load to be in the rear of the hinge for each section.
4. Cut several wooden templates, and pad with felt, to use in supporting the load by jacks while loading (see Fig. 27).

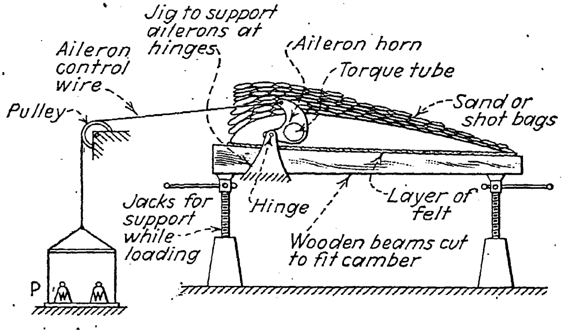

Jig to support ailerons at hinges
Aileron control wire
Aileron horn
Torque tube
Pulley
Sand or shot bags
Jacks for support while loading
Hinge
Layer of felt
Wooden beams cut to fit camber
P
W
W

FIG. 27.—Static-test setup for aileron.

5. With the aileron rigged in place, and the supporting jacks in place apply the load according to the schedule.
6. Lower all the jacks at the same time, slowly, until the aileron carries the load.
7. If there is a failure, screw the jacks up again, remove the load, and examine.
8. If the failure is not in the strength members of the structure but is only of a secondary nature, re-apply the load and continue with the test.

43. Aileron Load Corresponding to Control Forces.—The relation between the aileron loading and the control force required by the pilot or the control mechanism is important. This relationship may be calculated as follows, assuming, for example, a force of 80 lb. exerted by the pilot. (NOTE: The student should consult the latest specifications by the Army, the Navy, or the CAA for requirements of actual service testing.)

1. Calculate the pull on the aileron control wire. (See Fig. 28.) We use the principle of the lever here. For example, in *a*, we have $80 \times R = P \times r$. If $R = 30$ in. and $r = 5$ in., then P is 480 lb. In the case of the wheel control, we have two levers applying the load P (see Figs. 28*b* and 28*c*).

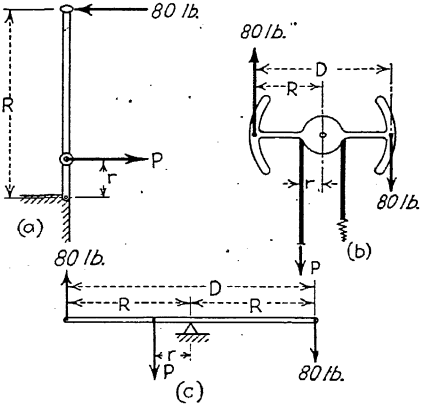


FIG. 28.—Leverage on aileron control wire.

In this case $Pr = 80 \times R + 80 \times R = 80 \times D$. For example, if the diameter of the wheel is 12 in. and the radius r of the control-wire pulley is 2 in., P is 480 lb.

2. The weight is placed on a platform A, as noted in Fig. 27 (P includes the weight of the platform). If the 12-lb.-loading schedule lifts the weight P from the floor, then the 12-lb. schedule is the test schedule. Increase P therefore so that it will not be lifted from the floor, and continue the test.

3. If the load P is not lifted from the floor it means that the loading schedule must be increased. To find this increase, remove weights from A until it barely lifts from the floor. Note the total load remaining. Call this p. For example, if P is 480 lb. and p is 240 lb., then the loading schedule must be doubled, making, in this case, 24 lb. per square foot. Also $w_{\max}$ is doubled; and in all cases the loading is increased in the same proportion as the loading schedule.

4. The loading schedule may be calculated directly, but this is not so simple, especially if the aileron is nonuniform in chord.

44. Static Test of Stabilizers and Elevators.—Specifications for static testing of stabilizers and elevators are given by the Army, the Navy, and the CAA. These regulations are frequently changed and are relatively complicated, making it impractical to include these in detail in an elementary text such as this. A simplified case is illustrated as follows:

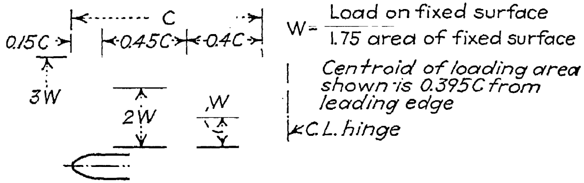

C
0.15C
0.45C
0.4C
3W
2W
W
W = Load on fixed surface / 1.75 area of fixed surface
Centroid of loading area shown is 0.395C from leading edge
C.L. hinge

FIG. 29.—Tail-load chord distribution. Forward portion.

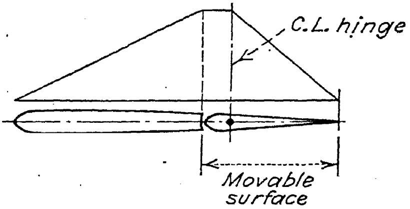


FIG. 30.—Tail-load chord distribution. Rear portion.

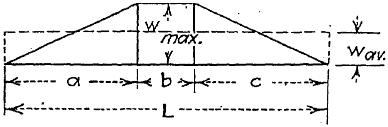


FIG. 31.—Relation between maximum load and average load.

See Figs. 29 and 30 for two assumed simplified loading conditions.

In the rear position (Fig. 30) the maximum load $w_{\max}$ is computed as follows:

Refer to Fig. 31. The total load per foot width is

$$w_{\text{av}}(a + b + c)$$

The total load computed on the basis of $w_{\max}$ is,

$$w_{\max}\left(b + \frac{a}{2} + \frac{c}{2}\right)$$

Equating these two expressions, we have

$$w_{\text{max}}\left(b + \frac{a}{2} + \frac{c}{2}\right) = w_{\text{av}}(a + b + c)$$

from which

$$w_{\text{max}} = \frac{(a + b + c)}{\left(b + \frac{a}{2} + \frac{c}{2}\right)} w_{\text{av}}$$

For example, if w_{av} is 20 lb. per square foot, a is 2 ft., b is 1 ft., and c is 2 ft., then $w_{\text{max}} = 20 \frac{(2 + 1 + 2)}{(1 + 1 + 1)} = \frac{20 \times 5}{3} = 33\frac{1}{3}$ lb. per square foot.

The test is carried out as explained in Par. 42 for the aileron, and in Par. 47 for a wing.

In computing the loading required to meet the specified conditions of forces on the controls, proceed as in Par. 43.

45. Static Test of Fin and Rudder.—For this test it will be necessary to support the fuselage on its side. If a separate test is to be made on the rudder, however, it will be more convenient to support it by the control wires and hinges, in a jig, similar in nature to that for the aileron shown in Fig. 27. The loading schedule is assumed. The distribution is specified as in Fig. 30.

The procedure for the remainder of the test is as outlined in Pars. 43 and 44.

46. Static Test of a Wing Rib.—See specifications of Army, Navy, or CAA for specific service tests. These specifications are frequently changed, so it is important that the latest requirements should be available. Only the elementary principles can be presented here.

For this test the wing rib is supported upside down by a jig, simulating the spars of the wing (see Fig. 32). The load is applied by straps, as noted in the figure. The load should be assigned by the instructor. The distribution of the load is usually specified in terms of concentrated loads, applied at specified percentages of the chord length from the leading edge.

The procedure in the test is as follows:

1. Set test stand out on the floor, near blackboard, where it is clear on all sides. Place horse or blocking under loading sling, with about 1 in. clearance.
2. Lay loading harness on floor and slide rib in place. Rib should be inverted. Place rib and harness on stub spars on stand. Adjust clips to

prevent rib from twisting when load is applied. Adjust load distribution stirrup so that hangars are all parallel and vertical.

3. Assign one man to chalk up weights and two men to load. The load should be increased 10 lb. at a time at intervals of 5 sec. Make sure that harness does not swing during loading. It must hang stationary.

4. Build up load until rib collapses. The last load unit added should not be included in the total breaking load. The breaking load is the ultimate strength of the rib. Include the weight of the harness.

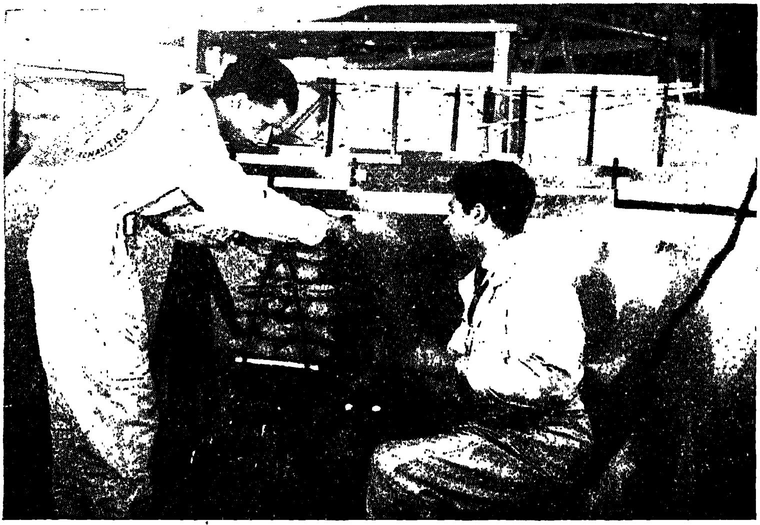


FIG. 32.—Static-testing a wing rib. (*Courtesy of Boeing School of Aeronautics.*)

5. Note points where fracture occurs, and type of failure. If more than one rib is tested, take the lowest breaking load, not the average, for use in the calculations.

6. Knowing the design load (determined as noted above by instructor) and ultimate strength, calculate the margins of safety for the rib in each of the design conditions.

$$\text{Margin of safety} = \frac{\text{ultimate strength}}{\text{design load}} - 1$$

For example: In a high angle of attack the design load is 295 lb. The rib may stand 350 lb., in which case the margin of safety would be $^{350}/_{295} - 1 =$ 0.18 or 18 per cent.

7. Determine the strength-weight ratio. The strength-weight ratio, or as it is often termed, the figure of merit, is the ratio between the ultimate strength and the weight of the structure tested.

$$\text{Strength-weight ratio} \quad \frac{\text{ultimate strength}}{\text{weight}}$$

An example of strength-weight ratio calculation is as follows:

Ultimate strength = 350 lb.
Weight of rib = 7½ oz.

$$\text{Strength-weight ratio} = \frac{350 \times 16}{7.5} \quad 746$$

8. Write up report on test, including ultimate strength obtained, margin of safety, and strength-weight ratio for both loading conditions.

47. Static-testing a Wing.—The portion of a wing covered by the fuselage, engine nacelle, etc., and the tips of the wing do not carry their full quota of load. When the area of the wing is reduced to provide for this condition, the remaining area is called the effective wing area. The effective wing loading is the gross weight of the airplane divided by the effective wing area. This loading is the basis for design and static testing. The effective wing loading is generally taken as pounds per square foot. The total load along the chord of any section of the wing in pounds per foot width will be the wing loading (pounds per square foot) multiplied by the chord in feet. The distribution of the load along the chord is made to simulate, as nearly as practicable, the actual distribution for the specified flight condition.

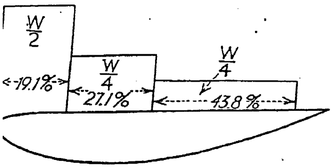


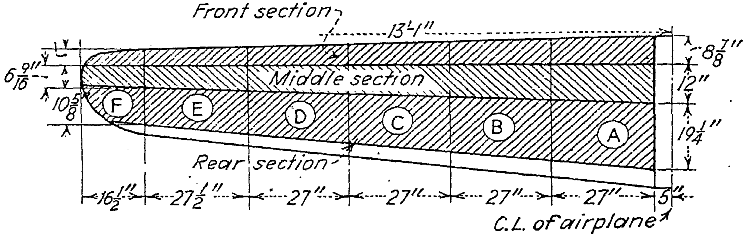
FIG. 33.—Approximate chord-load distribution in the static test of a wing.

Specifications for static testing of wings are given by the Army, Navy, and the CAA. These are frequently changed in accordance with the latest requirements and in most cases have become very complicated, making it impractical to present these in an elementary text. The student may learn much from the following simple example.

This example of static testing of a wing which we give here is one which is a classic in aeronautical literature. The test was made at Wright Field, the aeronautical experimental station of the U. S. Army Air Forces, in the development of the corrugated-stressed-skin-box-beam type of construction. This example is used because of its simplicity, neatness, and exactness. The procedure was as follows:

1. The chord load was distributed according to the Army requirements. The basic load (effective wing loading) was 7 lb. per square foot. The test was carried to destruction by increasing the load by a load factor of two for each test up to a failure at 11 factors; that is, 11 times the basic load of 7 lb. per square foot, or 77 lb. per square foot.[1]

2. A loading schedule was computed (see Fig. 34). As an example of the computation, consider a section at the root of the wing. The length of the chord at the root section is 44 in. If the leading and trailing edges of the wing were extended at the tip, the tip chord would be 22 in. The length of the tapered portion of the wing, as noted in the figure is 152 in. Since the wing tapers 22 in. in 152 in., the taper per inch is 22 divided by 152 which is 0.145 in. Thus the length of the chord at the middle of section *A* is $(44 - \frac{27}{2} \times 0.145) = 42.0$ in. $= 3.5$ ft. The area of the section is $(3.5 \times \frac{27}{12}) = 7.87$ sq. ft. Thus the basic load for the section is



LOAD SCHEDULE

Load	Section A			Section B			Section C			Section D			Section E			Section F		
Factor	F	M	R	F	M	R	F	M	R	F	M	R	F	M	R	F	M	R
2	49	25	25	43	22	21	37	19	18	30	16	15	24	12	12	11	6	5
4	104	53	52	91	46	45	78	40	38	64	33	32	51	26	25	23	12	11
6	159	81	79	149	70	69	119	61	58	98	50	49	78	40	38	35	18	17
7	186	95	93	173	82	81	139	72	68	115	59	57	91	47	44	41	21	20
8	213	109	107	197	94	93	159	83	78	132	68	65	104	54	50	47	24	23
9	240	123	121	221	106	105	179	94	88	149	77	73	117	61	56	53	27	26
10	267	137	135	245	118	117	199	105	98	166	86	81	130	68	62	59	30	29
11	294	151	149	269	130	130	219	116	108	183	95	89	143	75	68	65	33	32

FIG. 34.—Example of load schedule in the static test of a wing.

$$7.87 \times 7 = 55.09 \text{ lb.}$$

For a load factor of 2, the load required is 2×55.09 lb. $= 110.18$ lb. However, the wing itself weighs 1.3 lb. per square foot, and it acts as a part of the weight. Thus the weight of the portion of the wing designated by *A* is $5.87 \times 1.3 = 10.23$ lb. Hence, the total load to be applied is slightly less than 100 lb. According to Fig. 33, this load must be divided into four parts. The result is approximately 25 lb. per part. Section *F* (front section of Fig. 33) is assigned two parts designated in the loading schedule (neglecting the fraction) as 49 lb. *M* and *R* (middle and rear sections of Fig. 33), as may be noted, are scheduled for 25 lb. each. The schedule table of Fig.

---

[1] The wing was designed for a small monoplane of gross weight of 532 lb., wing span of 27 ft., and wing area of 76 sq. ft. A load factor of 11 requires a load of 11 × 532 lb. or 5,852 lb. total on the wing.

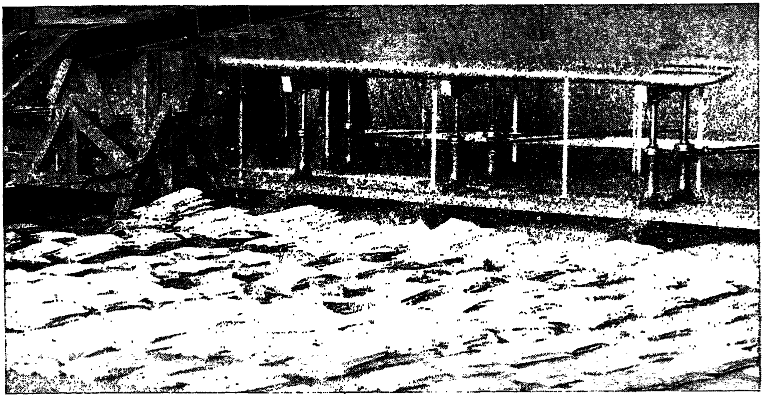


FIG. 35.—Preparation for static test of a wing. (*Courtesy of U. S. Army Air Forces.*)

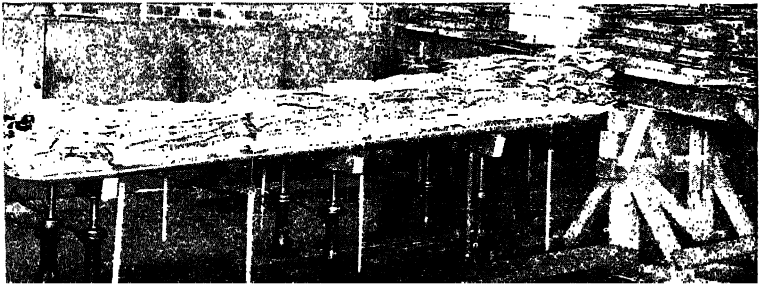


FIG. 36.—Static-testing a wing. (*Courtesy of U. S. Army Air Forces.*)

34 may be completed in the same manner as illustrated in the sample calculation.

3. Figure 35 shows the wing supported upside down by the fuselage wing fittings. The jacks are in place to support the load while the load is being applied. To prevent local failure of the wing skin by the jacks, three templates of wood are cut to fit the contour of the wing section, and then padded with felt. The jacks, as noted, are applied to these templates.

The sand and shot bags are laid out on the floor according to the schedule of loading (Fig. 34). Wooden scales are suspended from several points on the wing. A surveyor's transit, not shown, is set so that the movement of each scale may be read, thus giving the deflection of the wing at all scale points.

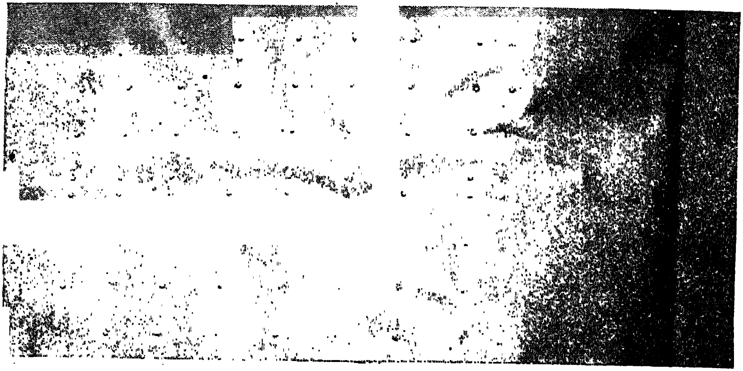


FIG. 37.—Wrinkling of wing skin, indicating a structural failure underneath. (*Courtesy of U. S. Army Air Forces.*)

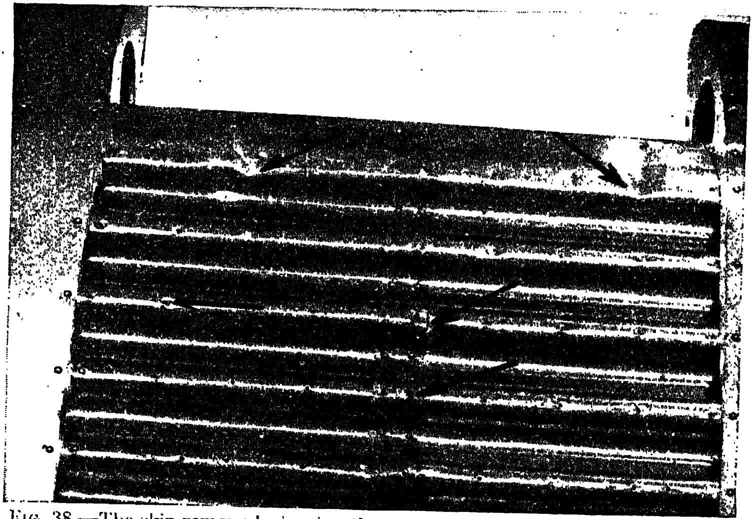


FIG. 38.—The skin removed, showing the structural failures indicated in Fig. 37. (*Courtesy of U. S. Army Air Forces.*)

4. Figure 36 shows the scheduled load applied to the wing. Figure 37 shows the wrinkled skin indicating a failure of the supporting structure underneath in compression. Figure 38 shows the skin removed, and how

the corrugated supporting structure failed in compression by wrinkling at the joints and at rivet holes.

48. Static Testing of Other Structural Parts.—Static testing is not limited to the tests described above. If the distribution and nature of the loading on a structure are known, the structure may be set up in jigs and the load applied to satisfy the required condition. For example, the determination of the efficiency of a splice in a cable (see Job Unit 51) is a static test. The tests illustrated in Figs. 120, 135, and 141 are static tests to determine the strength characteristics of a structural part.

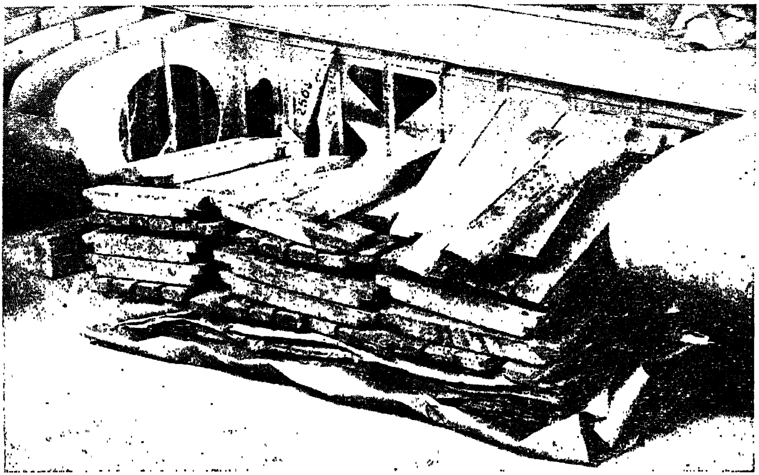


FIG. 39.—Static test of a leading edge. The test-load bars are of lead. (*Courtesy of U. S. Army Air Forces.*)

The static testing of riveted joints is a very good exercise in the study of riveting. As a matter of fact, most of the repairs on metal structures made by students as exercises may be static-tested for comparison with the strength of the original structure.

Figure 39 shows a static test of a leading-edge section of a wing. The test bars are of lead. In this case it was impossible to use jacks to catch the load, hence the total collapse.

Figure 40 shows the loading for testing the leading edge of a small wing.

Figure 41 shows a static test of an engine mount.

49. Dynamic Testing.—An example of dynamic testing is the landing-gear test. In this test the ability of the wheels, tires, shock absorbers, etc., to withstand the landing loads is determined. For example, consider the test, originated at Wright Field, for combining the shocks of landing cross wind. See Fig. 42. (The latest specifications on this test are not available for publication at the present time.)

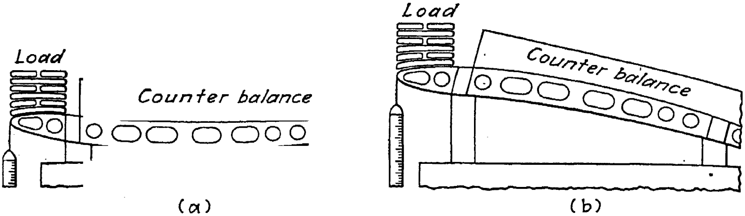


FIG. 40.—Static test of a leading edge.

1. *Arrangement for Test.*—The landing gear will be fastened securely to a heavy frame or to the fuselage, which is hinged at the tail end. The angle which the frame makes with the horizontal when the wheels are resting on the floor will be such that the center of gravity of the complete airplane will be vertically above the point of tangency of the wheels. To simulate the combination of direct load and side thrust, an auxiliary platform is placed under the wheels, built at an angle of 2½ degrees to the horizontal. The hinge at the tail end is

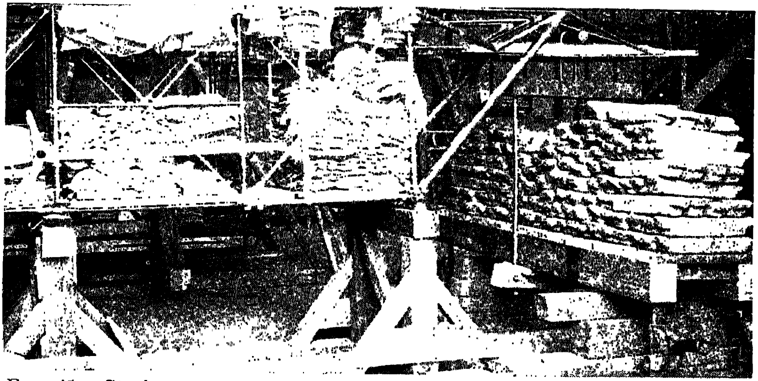


FIG. 41.—Static test of an engine mount. The test-load bars are of lead. (*Courtesy of U. S. Army Air Forces.*)

such as to allow for this angle, so that on impact the ratio of side load to down load is 1 to 6.

2. *Loading.*—Provision is made on the frame for so placing a load that the total load supported by the landing gear will be equal to the normal load on it when the airplane is in flying position. The load on the wheels will be determined with the frame or the fuselage in a horizontal position before the setup is complete. The difference between this load and the normal landing-gear load will be distributed at four points—engine bed, gasoline-tank cradle, wing attachment, and cockpits—in proportion to these respective loads in the complete airplane.

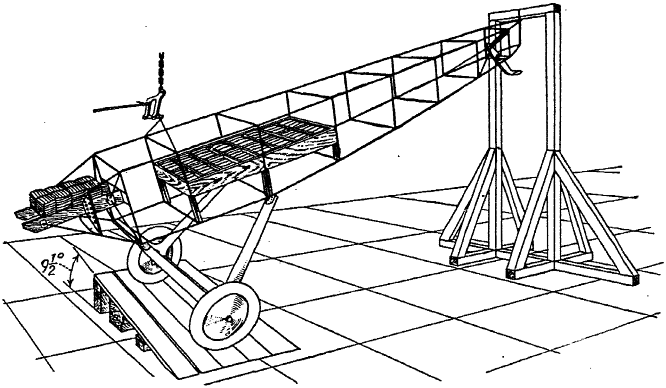


FIG. 42.—Dynamic test of a landing gear. (*Courtesy of U. S. Army Air Forces.*)

3. *Procedure.*—With all the load securely tied in place, the frame is raised a total of 6 in. and released, repeating the test and increasing the height of drop by successive increments until failure or the required height of drop is attained.

Review Questions

1. Define static and dynamic testing.

2. Where may specifications for static testing of airplane parts be found?

3. Explain how to find the center of gravity of an airplane.

4. Why is the location of the load in a transport airplane (passengers, mail, baggage, etc.) important?

5. What are the loading requirements for the static test of an aileron of a commercial airplane?

6. What strength is required of aileron control cables in a commercial airplane?

7. What is a load factor?

8. How is the static-test load applied on an airplane structure?

9. How is the side thrust on airplane wheels in a cross-wind landing simulated in the dynamic test of a landing gear?

10. How would you static-test a riveted joint? (See Job Unit 24.)

References

1. Airplane Airworthiness of Civil Air Regulations, CAR Part 04, Civil Aeronautics Administration, U. S. Department of Commerce.

2. Handbook of Instruction for Airplane Designers, Structures Tests, Air Corps, U. S. Army. (Not available to the public.)

Questions for Thought and Study of References

1. Describe the drop test (dynamic test) for landing gears as specified by the CAA. (See Ref. 1, Sec. 42.)

2. Describe the CAA tests specified for tail surfaces and ailerons. (See Ref. 1, Sec. 31.)

3. Describe the test specified for wing ribs. (See Ref. 1, Sec. 24.)

4. Describe the CAA tests for the control system of an airplane. (See Ref. 1, Sec. 35.)

5. How is the wing loading computed? (See Ref. 1.)

CHAPTER V

PROPERTIES AND USES OF METALS

Metals have properties most suitable for modern airplane construction. A knowledge of these properties is required in maintenance, since it is necessary to preserve the original physical properties during reconditioning or repair of metal structures.

50. Properties of Metals.—The essential properties (called mechanical or physical properties) of metals are:

1. Strength.
2. Elasticity.
3. Ductility.
4. Toughness.
5. Fatigue resistance.
6. Durability.
7. Hardness.

These properties are influenced by *alloying* the base metal; that is, by introducing into one metal, generally in the melted state, other elements. Alloying is a phase of metallurgy, a subject which is beyond the scope of this text. See References at the end of Chap. VI for bibliography on metallurgy.

51. Strength.—When a material has the ability to resist the external loads imposed, it is said to have strength. The internal resistance to applied forces, usually expressed as pounds per square inch, is called stress. For example, if a load is suspended by a rod, the stress is the pounds load divided by the area of cross section of the rod in square inches. The maximum strength of a material is called its ultimate strength. The stress calculation is based on the original size of the material.

52. Elasticity.—All materials will stretch, compress, bend, shear, or twist under applied loads. These distortions are called *strain.* If the loads are not too great, the materials will return to their original shape when the loads are removed. The deformation of aircraft metals under load is *proportional* to the applied load. This ratio is called *Hooke's law.*

The index of elasticity is termed the *modulus of elasticity,* often referred to as Young's modulus. It is generally designated by the letter E. *The modulus of elasticity is the stress divided by the* *strain per unit length.* For example, if a 3000-lb. weight suspended by a steel wire 100 in. long and 0.1 sq. in. in cross-sectional area stretches the wire 0.1 in., the modulus of elasticity, E, is computed as follows: The stress is the load, 3000 lb., divided by the area, 0.1 sq. in., which is 30,000 lb. per square inch. The unit strain is the stretch per inch. If the stretch per 100 in. is 0.1 in., the stretch per inch is 0.001 in. Hence,

$$E = \frac{\text{stress}}{\text{unit strain}} = \frac{30{,}000}{0.001} = 30{,}000{,}000 \text{ lb. per square inch}$$

A high modulus of elasticity indicates stiffness, a low modulus indicates flexibility. To illustrate this fact, the following experiment may be performed:

Select strips of sheet ⅛ in. thick, ¼ in. wide, and 20 in. long; one strip each of steel, aluminum alloy, and magnesium alloy. Clamp each strip side by side on a flat table top so that the extension beyond the table is 18 in. and there is freedom to flex in the vertical direction. On each free end of these strips fasten a half-pound weight. Comparison of these loaded metal strips shows an *appreciable bend in the steel; aluminum* about *three times* the deflection of steel under the same weight, and *magnesium* about *five times* the deflection of the steel strip. We note that the corresponding moduli of elasticity (Table II) are 29,000,000 lb. per square inch, 10,300,000 lb. per square inch, and 6,250,000 lb. per square inch, which have the inverse ratio of the magnitude of deflections.

TABLE II.—MODULUS OF ELASTICITY OF AIRPLANE METALS (AVERAGE VALUES)

Metals	E, Pounds per Square Inch
Magnesium alloys	6,250,000
Aluminum alloy 24ST, 17ST	10,300,000
Copper (drawn)	18,000,000
Monel	25,000,000
Chrome-molybdenum steel	29,000,000

Hooke's law of the proportionality of stress and strain does not hold for the full strength of the metal. The limit of the stress, greater than which the law does not apply, is called the proportional limit. For standard aircraft materials, the proportional limit is the same as the elastic limit. *The elastic limit of a material is the minimum stress at which the material suffers a permanent* *set;* that is, it will not return to its original shape and size when the load is removed.

The elastic limit of aircraft materials is about 60 to 80 per cent of the ultimate strength.

53. Ductility.—A metal which flows readily under pressure or deforms under load is said to possess ductility. *The measure of ductility is strain*—the deformation caused by the applied load.

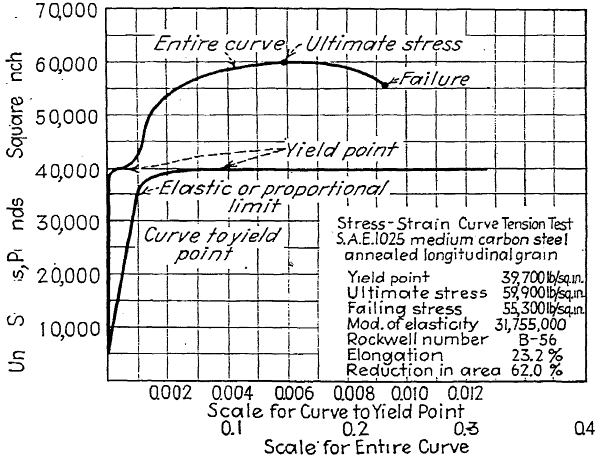


FIG. 43.—Stress-strain curve, showing physical properties of mild steel.

A tension load produces a stretch and reduction of cross-sectional area; a compressive load causes the length to decrease and the cross-sectional area to increase; a bending load produces a deflection; torsion causes the member to twist through an angle.

54. Stress-strain Relation for Metals.—The relation between load and deformation is shown on a typical stress-strain curve, Fig. 43, which graphically represents the behavior of the metal within the accuracy of testing equipment.

The *ultimate strength* (or stress) is not the failing stress because the ultimate strength is calculated on the basis of the original area. As the member stretches, however, the area of the cross section becomes less, necks down. The stress at failure based on the reduced area would be the maximum stress.

55. Toughness.—A dictionary definition of toughness is "having the quality of flexibility without brittleness." A tough metal is one which will stretch, under tension, before breaking. The magnitude of stretch indicates the magnitude of toughness. *The work (or energy) required to stretch a specimen till it breaks is a measure of its toughness.* The energy expended in stretching a specimen is the average force required times the strain. A little study will show the student that the area (Fig. 43) between the stress-strain curve and the strain axis is a measure of the energy expended in stretching the specimen to the breaking point. Thus of several materials, whose stress-strain curves are plotted on the same chart, the one having the greatest area between the curve and the strain axis is the toughest.

Toughness is also determined by dropping a weight on a standard beam of a material from increasing heights until the impact is sufficient to break the beam. The height of drop times the numerical value of the weight, which is energy, is the measure of the toughness of the material. This is called the impact test. *In most metals, high strength is obtained at the expense of toughness;* that is, in general, high-strength metals are more brittle than low-strength metals. This is not true, however, for stainless steel.

56. Fatigue Resistance.—The property of metals which enables them to withstand repeatedly applied loads or reversals of loading is called fatigue resistance. When a metal is subjected to a repetition of loading which exceeds the yield strength of the metal, gradual fragmentation becomes evident. This condition is revealed by microscopic changes similar to those appearing in Fig. 44. Incipient cracks develop as slippage increases to a point of separation in the crystals. If the stress is low enough, the repetition of loading or reversal of stress may be continued indefinably without failure. The highest stress which permits this indefinite repetition of loading or reversal of stress is called the *endurance limit* of the material. *This endurance limit is always less than the yield stress of the metal.*

Any surface condition which localizes stress, such as tool marks, surface scratches, forging defects, file marks, and sharp corners, hastens fatigue failure. These defects are called *stress raisers.*

The importance of fatigue resistance is obvious when one considers that all structural parts of an airplane are subjected to *severe vibration.*

57. Durability.—A durable metal is one which resists chemical attack and mechanical wear. The usual form of chemical attack is *corrosion.* Corrosion causes pitting. Pitting reduces the fatigue resistance of the material.

Corrosion is prevented by plating the surface with chromium, nickel, copper, or by applying the anodic treatment (see Par. 68). Alclad (see Par. 68) is designed to prevent corrosion. In general, with the exception of a copper-plated surface, the plated surface has requisite hardness to resist wear more effectively than the base metal.

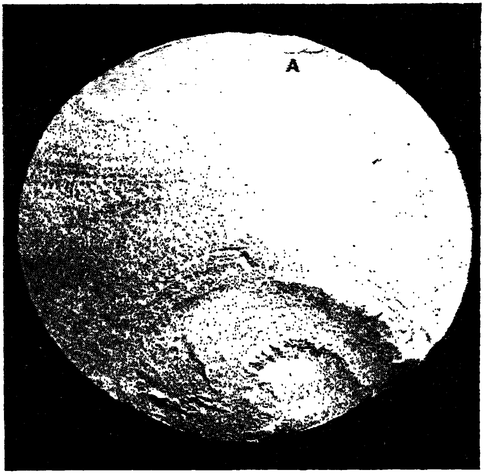


FIG. 44.—Slip planes in fatigue failure of axle after 1,670,000 cycles of stress. Magnification 4×. Origin of failure at *A*.

Impacts of abrasives which are picked up from the ground and carried in the air stream against metallic surfaces produce *scouring,* which lowers the fatigue resistance of the metal. Leading edges of airfoils, and empennage parts are areas affected. It has been found that scouring may be prevented by applying a sheet of rubber over the affected parts. *Rubber absorbs the impact of abrasive particles* more effectively than metal on these parts so long as the rubber remains fully resilient. Rubber which has hardened due to weathering readily cracks and has doubtful value in preserving the metal under it in durable condition.

A hard surface is the only safeguard against excessive wear. Hard surfaces are invariably brittle. The best wear-resistant surfaces are obtained by heat treatment or by electroplating (see Par. 67).

58. Hardness.—Hardness has come to mean several properties, that is, resistance of a material to indentation and penetration, resistance to abrasion and wear, resistance to cutting action, and restitution under dynamic loading. In other words, the term *hardness is understood to be the ability of a material to withstand permanent deformation.* Chemical changes caused by heat treatment affect the hardness of a material. One type of heat treatment will make a soft material hard, another type will make a hard material soft.

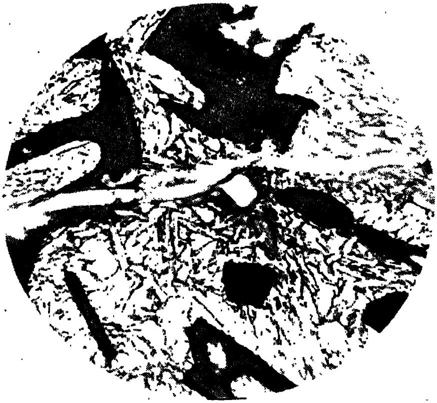


FIG. 45.—Microscratch through diamond in chilled Ni-Cr. iron. Magnification 1500 ×. Sodium picrate etch. (*Courtesy of Roy M. Allen.*)

In Fig. 45 appears a visual evidence of the effect of a hard constituent in a metallic matrix. A diamond, which is considered to be the hardest known substance, produced the path in the figure as it traveled, being deflected by a hard inclusion in the matrix. The orientation and chemical character of these microscopic particles largely determine the property of hardness in a given material.

Measurement of Hardness.—For measuring the hardness of metals, the most widely used methods are: (1) the *scleroscope,* (2) *the Brinell,* (3) the *Rockwell* method for measuring resistance to indentation and penetration, and (4) the *monotron*. An index of cutting resistance is determined by the scratch hardness test. The ordinary file may also be used to determine roughly whether or not a piece of metal is hard or soft.

Scleroscope.—The principle employed in the scleroscope is the drop and rebound of a diamond-pointed steel cylinder. This cylinder or hammer, as it is called, is allowed to drop upon the surface of the metal to be tested. The height of the rebound is indicated on the dial of the instrument and this reading is taken as the measure of hardness, the height of rebound of hardened steel being 100 on the scale. Thus all other readings are comparative. The scleroscope should always be set level when taking a reading. This is done by means of the plumb bob and the adjustable screws in the base.

The piece to be tested should always have a smooth surface and should be well supported, either on the flat anvil or in a V-block which is made to fit the base of the instrument, and held firmly while the test is made. It is generally desirable to take three or four readings at different places and then take an average. In no case should a reading be taken in the same spot twice.

The Brinell Test.—In the Brinell method, a hardened steel ball is pressed into the smooth surface of the metal to be tested. The indentation thus produced is measured with a microscope. From the spherical area of the indentation and the pressure applied, the stress per unit area when the ball comes to rest may be calculated and the hardness number obtained.

The hardness number may be calculated by means of the formula:

$$H = \frac{\pi D}{2}\left(D - \sqrt{D^2 - d^2}\right)$$

where H = the Brinell hardness number.
P = load applied.
D = diameter of ball.
d = diameter of ball impression.

In order to obtain standard results, the diameter of the ball should be 10 mm. (±0.0025 mm.) and the weight applied to steels should be 3,000 kg. for 30 sec. For softer metals, such as brasses, bronzes, etc., a load of 500 kg. is to be applied for 30 sec.

Speed of Loading in Brinell Test.—Frequent tests on the Brinell hardness tester have shown an increase in hardness for short periods of loading, and a decrease in hardness number for extended periods of loading. These effects were measured in tests[1] performed at the experimental laboratories of the Krupp works at Essen, Germany. The curves which were determined by these tests on soft iron show that, for maximum pressure applied during 5 min., equilibrium is not established for different diameters of ball penetrator. *For hard steels one minute was found to be necessary to produce equilibrium,* because of the reduced ability of hard metal to flow under the continued pressure of the penetrator. Tests on hard iron with duration of loading of 10 sec. produced results within 3 per cent of the value obtained for sustained loading of 5 min. The same error for soft iron was obtained for 20 sec. of sustained loading.

Metals such as zinc require 2 or 3 min. for the same results. Copper showed variations in loading time have little effect, because of strain hardening effects of copper under load. The usual time of loading in practice is 30 sec.

Brinell hardness numbers corresponding to a given load and diameter of impression have been worked out in the form of a table, so that hardness numbers can be read directly. The Brinell test is used quite extensively in commercial practice for checking uniformity of metal and for accepting metals for service.

59. The Principle of the Rockwell Test.—Under certain fixed conditions of load the Rockwell tester measures the depth of residual penetration by a steel ball or diamond cone. By subtracting the penetration from an arbitrary constant, a number is derived which expresses the hardness.

A minor load of 10 kg. is first applied, which seats the penetrator in the surface of the piece being tested and thus holds it in position. The dial is then set to zero and the major load is applied. (When using the diamond cone, the total major load is 150 kg., and when the $\frac{1}{16}$-in. steel ball is used, the major load is 100 kg.) After the pointer comes to rest, the major load is removed, leaving the minor load still on.

As *Rockwell numbers* are based on the difference between the depth of penetration at major and minor load, it will be evident that the greater this difference, *the less the hardness number, and*

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[1] MAILANDER, R., *Kruppacher Monatschefte,* vol. 5, October, 1924.

the softer the material. This difference is automatically registered when the major load is released (the minor load still being applied) by a reversed scale on the indicator dial, which thus reads the Rockwell hardness number directly.

On examining the dial, it will be found that there are two scales. The black scale and the letter *C* are used when testing with the diamond-pointed cone and the 150-kg. load. The red scale and the letter *B* are used in connection with the 100-kg. load and the 1/16-in. steel-ball penetrator. All readings should be prefixed by the letter *B* or *C*, showing which scale was used.

As the Rockwell scale is based on depth measurements, the *cone penetrator* gives the more accurate readings on hard metals, while the steel ball is best adapted for the softer metals. Where the readings fall below *C*-20, it is preferable to test the material with the 1/16-in. ball. Readings on the *B* scale are not generally taken higher than *B*-100, at which point it is advisable to change to the *C* scale, using the cone penetrator. Measuring hardness greater than *B*-100 is liable to deform the 1/16-in. ball, thus destroying its usefulness for further testing.

The machine is also provided with a means of regulating the *rate* of application of the load. The standard time when using the 100-kg. load is 5 sec., and when the 150-kg. load is used, the time is 4 sec. All work to be tested should be smooth and solidly supported, either on a flat anvil or one with a V-notch for round pieces. Rockwell hardness of thin-gauge metals is determined by the *superficial hardness tester.*

60. Types of Failure.—The types of failures which may occur in a structure are as follows:

Tension Members.—The elongation of the member will continue at the rate indicated by the modulus of elasticity until the elastic limit is reached. If the load is released prior to this point, all signs of strain disappear. If released at a point above the elastic limit, a "permanent set" is noticed. *If the load is again applied, a new elastic limit is apparent, higher than the first one found.*

The apparent effect of the load after reaching the elastic limit, is a rapid extension of the specimen. This will soon be apparent, in the case of ductile materials, by the "necking down" of the specimen and rupture in the smallest section.

The nature of the *rupture* will vary with the material, and its *physical working* prior to test. Good ductile steels have a cup shaped rupture with a silky appearance. Inferior steels show irregular ruptures, and if the material is very inferior several "elastic limits" will be noted.

Compression Members.—The nature of stress and strain in compression members is far more complex than in tension members. Very short compression members fail by *crushing.* Slightly longer members fail by diagonal shear, and long members fail in *bending* (*buckling*).

Shear Members.—Such members are rivets, bolts, pins, etc. It is seldom that pure shear is experienced. It is usually accompanied by crushing and often by bending (see Chap. XI, on Riveting).

Members in Bending.—The nature of stress and strain in bending combines the three types of failure noted above. In other words members in bending can fail either in tension, compression or in shear and sometimes by crushing. An ideal beam would have a material distribution that would fail simultaneously under all the above.

61. Physical Testing on Metals.—Standardized tests are extant for determining the physical properties of metals. These tests are tension, compression, bending, impact, and fatigue tests.

The *tension test* is made on standard specimens either round or flat with standard testing machines whenever possible. In this test the *yield-point strength, ultimate strength, elongation* and *reduction in area* are usually determined.

The *compression test* is performed on short specimens for which the ratio of length to radius is less than unity, or on longer specimens which act as column members using the standard compression-testing machine.

The *bending test* is made by bending a flat or round specimen around a bar having a diameter equal to the thickness or diameter of the specimen. During such bend tests the specimen is examined for surface *cracks* and the *angle of bend* measured. For *maximum ductility* in forming operations, the metals which are tested usually are required to bend double; that is, 180 deg. Often this bend test is applied to metals while hot to discover *hot shortness* (brittleness) at elevated temperatures.

The *impact tests* are standardized under the names of Izod and Charpy. For standard flat or round specimens which are notched in the center to insure localized fracture, the impact-test measures the energy the specimen absorbs in fracturing. This energy is given the designation of impact number. The impact test, therefore, represents a quick method of determining the *toughness* of metal, the metal with a low impact number indication a brittle metal.

The *fatigue test* combines the means of imposing a stress upon the end, or the center of a smoothly polished specimen, and a method of repeating this stress. All tests include a rapid reversal of stress for extended periods of time, or until fracture occurs in the specimens.

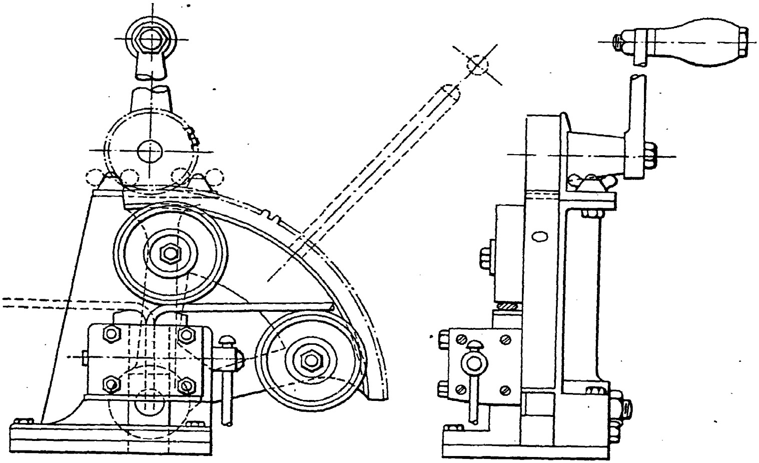

FIG. 46.—Reverse bend-testing machine for testing wires. (*Courtesy of U. S. Army Air Forces.*)

Unsuspected conditions which prevail within a metal are revealed by *radiographic* (X-ray or γ-ray) *study* which is performed at the present stage of development according to no prescribed standard.

Defects are located by the position of a magnetic material distributed on the surface of a machined part which has previously been magnetized. This method and its use in detecting fatigue cracks, imperfect welds, heat-treatment cracks due to quenching, and grinding cracks are presented in Chap. VI.

62. Properties of Aircraft Steels.—Steels of various compositions are used in aircraft parts. The typical steels, which the

TABLE III.—AVIATION

Material	S.A.E.	Specifications		Chemical		
		U. S. Army	U. S. Navy	C	Mn	Si
Carbon steel sheet				0.02	0.04	
Carbon steel sheet	1025	57-136-3	47S17	0.20 0.30	0.50 0.80	
Carbon steel bar	1025	AN-QQ-S-646		0.20 0.30	0.50 0.80	
Carbon steel tube	1025	AN-WW-T-646		0.20 0.30	0.50 0.80	
Carbon steel wire	1095	48-7	47S4	0.9–1.00 0.7–1.05	0.70 0.50	
Carbon steel free machine	1112	57-107		0.10	0.80	
Chrome-molybdenum sheet	X-4130	AN-QQ-S-685		0.25 0.35	0.40 0.60	
Chrome-molybdenum bar	X-4130	AN-QQ-S-684		0.25 0.35	0.40 0.60	
Chrome-molybdenum tube	X-4130	57-180-2	44T18	0.25 0.35	0.40 0.60	
Chrome-molybdenum tube resistance weld.	X-4130	10241	M-526	0.35 0.45	0.50 0.80	0.15 0.30
3½ nickel bar	2330	57-107-17		0.25 0.35	0.50 0.80	0.15 0.35
Chrome-vanadium sheet	6130	57-107-16	47S12	0.25 0.35	0.50 0.80	
Chrome-nickel sheet annealed	18-8	AN-QQ-S-757		0.08‡	0.20 0.70	0.70‡
Chrome-nickel sheet hard tempers	18-8	AN-QQ-S-772		0.15	0.70	0.70
Drill rod		57-108	46S9	0.90	0.70	
Chrome-nickel tube	18-8	AN-WW-T-855		0.07	0.70	0.70
Chrome-nickel molybdenum	X-4340	AN-QQ-S-756				
Corrosion—heat resistant	51210	10080		0.08–12	0.70	0.70
Chrome-nickel forgings				0.40 0.50	0.70	0.30 0.80

* Average values.
† Varies with thickness.
‡ Maximum.
§ 5.5X carbon (actual C-0.08).
‖ Several tempers available.
¶ After heat treatment.
** Backing is carbon steel.
From *American Welding Journal*, September, 1936; revised 1941.

Materials—Ferrous

composition, %				Ult. tensile* str., kips	Yield strength	Elon. 2 in., %	Min. red. area, %	Use
Ni	Cr	Mo	Others					
			P-.006 S-.004	35				Exhaust stacks
				55	36,000	22		Fittings
				55	36,000	22		Miscellaneous parts
				55	36,000	22		Miscellaneous parts
			P-0.04 S-.045					Washers, tail skids, clips
			S-.4					Screws, fastenings
	0.80 1.10	0.15 0.25		90	70,000	10† 15		Structures, fittings
	0.80 1.10	0.15 0.25		125	100,000	18¶		Structures, fittings
	0.80 1.10	0.15 0.25		90 95	70,000 75,000	15† 10		Structures, fittings
	0.80 1.10	0.15 0.25		125	100,000	18¶		Nonstructural parts
3.25 3.75				125	100,000	17	50¶	Unwelded parts, axles
	0.80 1.10		Va. 0.15					Propeller hubs in forgings
8 10	17 20		Ti§	80	35,000	40		Exhaust stacks
7‡	17‡			125 185	90,000 150,000	10 5		Structures, wings, fire walls, nacelles
				125	100,000	12	25	
8 11.5 8	17 20 17	**	Ti	80 185	35,000 140,000	50‖ 8		Structures, exhaust manifolds
				170	150,000	15	25	Landing-gear parts
10	20			60		40		
13 15	13 15	0.50	Va 1.75 3.0					Gears

TABLE IV.—AVIATION

Material	S.A.E.	Specifications			Chemical		
		U. S. Army	U. S. Navy	Federal	Mg	Mn	Si
Aluminum bar			46-A-3	QQ-A-411			
sheet				QQ-A-561	0.2		0.2
Aluminum, 4%		AN-QQ-A-402			95.6	0.4	
Aluminum alloy 24S bar			46-A-9	QQ-A-354			
sheet	24	11067†	46-A-8	QQ-A-362	1.5	0.60	
Aluminum alloy die castings		AN-QQ-A-366		QQ-A-591			5.0
Aluminum alloy	25	57-151-1	47-A-2	QQ-A-561			
Aluminum alloy	25	46	46-A-3	QQ-A-411	0.2		0.2
Aluminum-copper-magnesium 17S bar			46-A-4	QQ-A-351	0.3		
sheet			47-A-3	QQ-A-353			
tube			44-T-21	WW-T-786			
Aluminum-copper-magnesium 1.5 bar							
sheet				11066	0.3		
tube				10235			
Aluminum-magnesium-chromium tube			47-A-11		2.5		
Aluminum-manganese bar				QQ-A-356			
sheet				QQ-A-359			
tube			44-T-20				
Aluminum-silicon castings		57-72					5.0
tube							
Beryllium-copper bar			11070				
sheet				M-328			
tube							
Brass bar			47-B-2 Gr-1				
sheet				QQ-B-611 Var. Grs.			
Bronze-aluminum		11083	46-N-5				
Copper bar			47-C-2				
sheet				QQ-C-501			
tube				WW-T-799 Type-N			
Copper-nickel (Monel) bar				QQ-N-281			
sheet				QQ-N-281		3.0	
tube			46-M-7				
Copper-silicon		11065†					5.0
Magnesium-aluminum					95.6	0.4	
Magnesium alloy AM-3-S					99.15	1.85	
Magnesium alloy AM-240 AM-241	304	AN-QQ-A-383			0.2–0.3	Bal.	
Magnesium alloy AM-53-S					91 92	Bal.	
Magnesium alloy		AN-QQ-A-383		QQ-A-596			
Magnesium alloy AM-57-S			46-A-7	QQ-A-367			
Magnesium alloy AM-61-S	26	11321	M-126				
Magnesium alloy		11320	M-314				
Manganese-bronze bar			46-B-15				
sheet				QQ-B-721		8.0	
Nickel-chromium-iron		11082†					
Nickel-copper-aluminum bar		11083					
sheet			46-N-5				
Phosphor-bronze bar			46-B-14				
sheet				QQ-B-746			

*½ hard. † Air Forces. ‡ Heat-treated.

composition, %							Ult. tensile str., kips	Yield strength, kips	Elon. 2 in. %	Aircraft uses
Cu	Ni	Cr	Al	Fe	Be	Others				
			99 Min.	Bal.			17*	9	9	Nonstructural, tanks
			4.0							Cast and heat-treated
4.5							26 68 70	10 45 55	20 19 13	24SO 24ST Structural 24SRT fittings
4.0										Junction boxes, small covers
			99 Min.	Bal.			18	8	18	2-S sheet 2-S bar, wire, rod shapes
2.5			Bal.				33–55	15–40	20	Heat-treated Sand castings General purpose
2.5				Bal.			35–65	15–40	20	Machine fittings Miscellaneous structural Struts
		0.25	Bal.				31–39	34	8	Tanks and fairings
							15–27			Sand castings
			Bal.	Trace			19	9	3	Nonstructural fittings
95.0				Bal.	3.0		196		3	Wire Flat springs Flat springs
62.0						2.8SN 28.0ZN	48	40	22	Wire rods sheet
8.0	1.5		Bal.				62	52	8	Bearings, gears
99							35		18	Electrodes Tubing, plumbing
32	62			3.0			80–110	65	18	Tubing, rivets
90							55	45	12	Everdur—sheet-bar
			4.0				37 28	10–16 10	8 9	Hard rolled Annealed
							34	24	5	Hard rolled Heat-treated and rolled
			10-8				28–30		1–2	Die casting Magnesium
			8.0 9.0							Extruded
							25 As cast 30–38 HT‡	11–13	3–8	Permanent mold
							38–42	22–28	6–12	Hot pressings
							33–38	18–24	5–10	Hammer forgings
										Bars, rod, and wire
							65	40	4	Springs, rods, gears Flat springs
	8.0	3.0		Bal.			85–125	75–85	20	Heat-resistant parts
8.0	1.5		Bal.				35		18	Aluminum bronze Gears, bushings
										Bearings, bushings, gears Flat springs

airplane mechanic must repair and replace, are listed, with the most important properties, in Table III.

63. Properties of Aluminum Alloys.—The alloys of aluminum constitute the largest weight of any single metal used in the modern all-metal plane. The principal characteristics of these alloys and those of magnesium are outlined in Table IV.

Review Questions

1. Distinguish between stress and strain.

2. What is the ultimate tensile stress of a bar of steel sustaining a maximum load of 20,000 lb. based on the original diameter of 0.505 in. and also based on the final diameter of 0.4 in.?

3. Determine the tensile stress in a tube of 1½ in. o. d. and 18-gauge wall thickness (0.049 in.) under a load of 20,600 lb. *Ans.* 95,500 lb. per square inch.

4. How does the modulus of elasticity furnish a direct basis of comparision of stress of metals under the same strain?

5. If a chrome-molybdenum-steel (S. A. E. 4130) strut is substituted for a strut (24ST) of equal dimension, determine the percentage increase in strength.

6. Explain the precautions necessary to obtain a reliable Brinell hardness number.

7. What errors in the operation of the scleroscope produces an erroneous hardness reading?

8. Describe the kinds of stresses in bending and indicate their distribution. Why would it be inadvisable to have failure of each under stress simultaneously?

9. Name the principal standard tests for physical properties of metals.

10. What is meant by toughness? How is it measured?

11. Define fatigue resistance. If a metal has sufficient strength to support a steady load, what conditions must be met for such metal to withstand fatigue?

12. Explain why the breaking strength of mild steel is not its ultimate strength.

13. What is meant by ductility? How is this property measured?

14. Name the tempers by which aluminum alloys are designated.

15. *a.* Is rubber a durable material? Why?

b. Where is rubber used in aircraft to resist wear?

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Questions for Thought and Study of References

1. What is meant by wrought alloy? (Ref. 5.)

2. Name the tempers by which magnesium alloys are designated. (Ref. 8.)

3. What S. A. E. steel is largely used in welded aircraft structural parts? (Ref. 4.)

4. What properties of stainless steel make it suitable for exhaust stacks, tanks, and propeller blades? (Ref. 4.)

5. Name briefly the application of forgings and castings which have been used in aircraft construction. (Ref. 3.)

6. In what respect are alloys high in magnesium content adaptable to aircraft construction? (Ref. 1.)

7. Describe a method of testing a round tensile specimen and a flat tensile specimen. (Refs. 1 and 3.)

8. Define the steels by chemical content designated by S. A. E. 30905 and S. A. E. 71360.

9. What are the effects of contact lengths in drawing on the physical properties? (Ref. 11.)

10. What types of furnaces are used for precipitation heat treatment of artificially aged alloys of strong aluminum alloys? (Ref. 9.)

11. How does the addition of nickel in the stainless-steel alloys affect the rate of work-hardening? (Ref. 10.)

12. Indicate the weight-saving possibilities of a beryllium alloy. (Ref. 12.)

CHAPTER VI

MAINTENANCE OF METALS

The large majority of aircraft metals possess superior physical properties of strength, toughness, hardness, and ductility because of heat treatment. Continuation of these properties in repaired sections requires a knowledge of the heat-treatment process best suited to the metal which is used.

64. Heat Treatment.—For each composition of metal, heat treatment consists in heating and cooling that metal through a *range* temperature while in the solid state. Both ferrous metals (those composed largely of iron) and nonferrous metals (those deriving their properties, in the absence of iron, from such as aluminum, copper, and/or magnesium) respond to heat treatment. All of the metals react similarly to annealing, hardening, and tempering. (These terms are defined in the following paragraphs.)

The heating and cooling rate determines the internal crystalline structure (called matrix) of the metal. Transformation of this crystalline matrix occurs during the following operations:

1. *Heating* the metal to a high temperature, below or above its critical temperature.
2. *Holding* (or soaking) the metal at the elevated temperature for a sufficient time to saturate the metal with heat and to permit the change in grain size and form to be complete.
3. *Cooling* the metal to room temperature in air, oil, water, or heated baths.

The temperatures at which the changes in size and form of crystal or grain occurs are called critical temperatures.

The relation between temperature and composition for iron-carbon steel is shown in the *critical-range diagram* (Fig. 47*a*). The importance of this diagram as a guide in heat-treatment operations is indicated, for example, in the heating, soaking, and cooling cycle for a carbon steel of 0.35 per cent carbon content (Fig. 47*a*). It is to be noted that the original grain size is transformed at the upper critical temperature of 1410°F. An additional change, which is not shown, is the *absorption of carbon* by the iron in finely dispersed form. By heating and holding (soaking) this mass slightly in excess of the upper critical temperature, its complete transformation is assured. *Overheating* while hastening the reaction must be done below that temperature where grain growth begins, usually, for steel, 150 to 200°F. above the upper critical temperature.

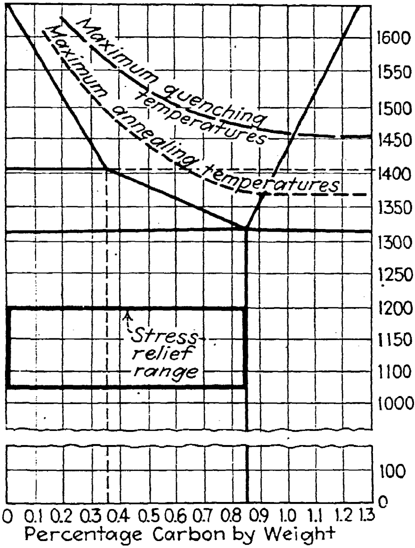


FIG. 47*a*.—Critical-range diagram for steel.

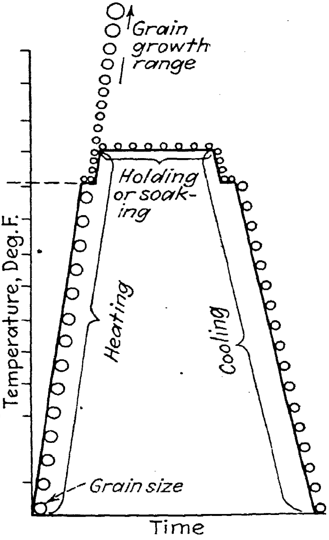


FIG. 47*b*.—Heat treatment cycle 0.35 per cent carbon steel.

The *rate of cooling* which is regulated by using air, oil, or water is indicated in Fig. 47*b*. *Air cooling softens the metal* without much change in grain size. *Oil and water cooling produce strength, toughness, and hardness, with a decrease in ductility and grain size.* Similar changes occur with *steels of different carbon percentages* (except at lower temperatures) until 0.85-per cent carbon steel is reached, then the higher carbon content requires an increase in the temperature at which the transformations occur. For the total range of carbon in steel the critical temperatures are shown in Fig. 47*a* for annealing and hardening. Each steel has its own *optimum temperature* for heat treatment, varying with carbon and alloy content. (See Fig. 47*a* for recommended heat treatment.)

The diagram, which is the guide in the heat treatment of duralumin (a strong aluminum alloy in which copper is the principal alloying element) is given in Fig. 48. *Aluminum alloys,* in general, are more sensitive to heating than *iron-carbon steels* and require accurate temperature control within 5°F. of the critical temperature. During heat treatment of aluminum alloys, the metal is heated to a temperature (less than melting) at which component elements are mutually soluble. From this solid solution, *quenching* retains the conditions formerly existing at elevated temperatures. This cycle is termed, quite frequently, the *solution heat treatment.* Much like salt dissolving in water, *copper is dissolved in the solid solution of aluminum.*

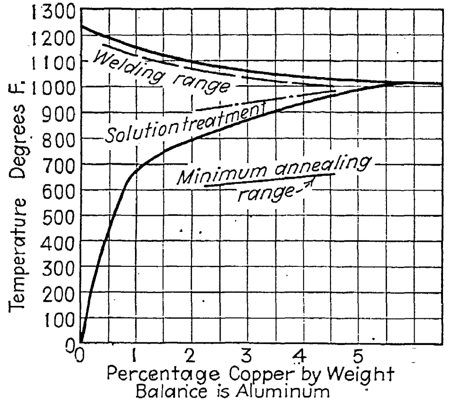


FIG. 48.—Critical-range diagram for aluminum-copper alloys.

After quenching, the alloying elements (held in solid solution) are *precipitated* in finely dispersed particles. This precipitation occurs at room temperature in alloys which *age naturally,* and at an elevated temperature (nearly 300°F.) in alloys which *age artificially.* This process is known as *precipitation heat treatment.*

65. Importance of Grain Size.—When a metal alloy is polished and etched with a suitable chemical in the manner outlined in Par. 77, the metallic grains (crystals) and their boundary cement stand out in relief (Fig. 49). The intercrystalline areas are composed of a bonding cement and a composite of the metals present. When the metal is loaded until failure develops (as has been demonstrated) *the grain slips within itself primarily and in the intercrystalline areas secondarily.* It is desirable, therefore, so to treat the metal as to obtain the *maximum intercrystalline matrix* and the *minimum amount of grain.* This condition exists when the grain size is the smallest.

Overheating of steel causes enlargement of the crystals (called grain growth). (See Fig. 50.) Since large grains break down under load more readily than the smaller grains, *existence of a large grained structure signifies lack of resistance to shock or vibration.* For this reason, large-grained metal, originating almost entirely during heat treatment, is undesirable in aircraft construction and repair.

66. Annealing.—There are three recognizable kinds of annealing for steel:

1. Stress-relief annealing.
2. Full annealing.
3. Normalizing.

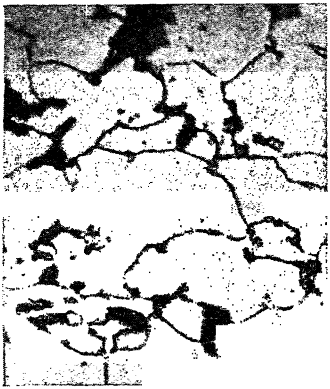


FIG. 49.—Photomicrograph of low-carbon steel. Magnification 500 ×.

The *stress-relief anneal* is applied for removal of the *residual stresses* in welded joints or severely cold-worked parts. This operation consists of heating the steel to a dark cherry color, at about 1100°F. (Fig. 47*a*), followed by cooling the parts to room temperature in air. Provided the heating is not too prolonged at elevated temperature, the grain size is not affected and the *locked-up stresses* are largely removed. The welding torch is often used for the heating.

Full annealing of steel consists in heating and holding the parts above the upper critical range (Fig. 47*a*) until heated throughout, and the grain has been refined, and then cooling it in air. The results are: *a softer steel, relief of residual stresses, greater ductility, and lowered strength.* The annealing-temperature range to which the steel must be heated and soaked before air cooling can proceed, is shown in Fig. 47*a*.

Normalizing, in its effect upon steel, is similar to annealing, although obtained by a slightly different heat treatment. The normalizing temperature is made higher than the temperature for annealing to obtain better *solubility of carbon* in iron during a shorter heating interval than the interval required for annealing. *Normalized parts are cooled in still air.* The combination of full annealing following normalizing is quite common to insure a fine crystalline structure, usually absent in normalizing treatment.

Annealing of aluminum alloys is done at or near the temperature of recrystallization (Fig. 48), with the result that the metal is softened and made more malleable without much change in grain size. The annealing range for copper bearing aluminum alloys or the so-called *duralumin* is given in Fig. 48. For other aluminum alloys there is a correct temperature which must be obtained by experience.

Hardening is the heating of metal to slightly above the temperature at which grain refinement take place, followed by rapid cooling in oil or water. The grain structure at the completion of cooling remains practically the same as its structure at the time of quenching. The *residual strains* caused by rapid cooling *prestress* the metal. Reheating to temperatures below the lower critical temperature for the particular alloy (Fig. 48) relieves these strains. For steel this reheating followed by quenching in oil or water, is called *tempering*.

Tempering decreases the hardness of steel and increases its toughness with relief of the most severe internal stress.

Hardened and tempered metal is softened by reheating, so that good judgement must be exercised in heating hardened or aluminum alloy parts.

While *aluminum alloys*, which have natural aging properties, are not tempered, their condition corresponding to temper is designated such as *dead soft*, *half hard*, and *maximum temper*. *Aluminum alloys which develop optimum properties by the precipitation treatment are artificially aged or tempered.*

Temper, as applied to aluminum alloys, may mean a soft alloy or a hard alloy, depending upon its heat treatment. In natural and artificial aging, the hardness, strength, and toughness of aluminum alloys is due to the interlocking character of the precipitated elements which makes slip along crystal planes difficult. A simple analogy of this phenomenon is the effect of sand on icy pavements in increasing traction.

67. Special Steel Treatment.—Certain parts requiring a wear-resistant surface, yet possessing a tough, resilient center core are soaked at elevated temperatures in contact with a *carbonaceous material*, such as hardwood, peach-pit charcoal, or natural gas, for several hours. This process is called *carburizing*. The iron absorbs sufficient carbon to become a high-carbon steel at the surface, leaving a low-carbon-steel center. When this carburized steel is hardened and tempered, the extremely hard surface is wear-resistant and the center or core is strong, tough, and elastic. Roller and ball bearings, crankpins, and piston pins are examples of parts which have been carburized.

Nitriding is performed by soaking a special alloy steel in anhydrous ammonia below the lower critical temperature (Fig. 47*a*). Absorption of nitrogen as iron nitrides in the surface produces greater hardness than carburized steel but to a lesser depth. The nitrided surface withstands higher temperatures and resists wear and corrosion better than does carburized steel. Engine-cylinder barrels and gears have been successfully nitrided, with less distortion and greater durability than is possible with carburizing treatment.

68. Special Treatment of Aluminum Alloys to Prevent Corrosion. *Anodizing.*—The anodic treatment is an electrolytic process whereby the aluminum parts, at the positive terminal in a 9.25 per cent aqueous solution of a chromic acid, are oxidized. An electric current is passed through the bath according to the following schedule:

1. Increase voltage from 0 to 40 volts in first 15 min.
2. Hold at 40 volts for 35 min.
3. Increase to 50 volts in 5 min.
4. Hold at 50 volts for 5 min.

The parts are then removed and washed thoroughly in warm water.

Cold-drawn parts are usually given the anodic treatment after thorough cleaning prior to the drawing operation. Heat-treated aluminum parts are given the anodic treatment following the heat treatment. The parts are made ready for installation by priming with a suitable primer.

Alclad is aluminum-alloy sheet into the surface of which is rolled a thin coating of pure aluminum.

69. Important Factors in Heat Treatment.—The results of heat treatment are influenced by such effects as (1) rate of heating, (2) time of soaking, (3) rate of cooling, (4) temperature control, (5) composition.

70. Rate of Heating.—The time necessary to bring a part or load to the proper heat-treating temperature depends upon the *size* of the part or load, the *thickness* of the metal, and the *type of heating equipment* employed. Rapid heating affects only the surface. Instead of producing the critical transformation in the entire mass, the *rapid heating causes distortion or warpage.* Thin sections heat through more readily than thick sections; only by warping is the expansion of the thin metal of a part absorbed. *Gradual heating,* therefore, becomes necessary. A common procedure is to rotate the part or parts through a half turn periodically (every 20 sec.) to equalize the heating.

TABLE V.—SOAKING TIME FOR ALUMINUM ALLOYS*

Thickness, in.	Time for various alloys, min.		
	17S and Alclad 17S†	24S	Alclad 24S
Up to 0.032	20	30	20
0.032–⅛	20	30	30
⅛–¼	30	40	40
Over ¼	60	60	60

* Soaking time starts when the metal (or the molten bath) reaches a temperature within the range specified in Table VI.

† The soaking time shown for 17S can also be used for alloys 53S and 61S.

Courtesy of Aluminum Company of America.

The *furnace capacity must be ample* enough to insure heating of its load throughout. Stuffing of the heating furnace or bath prevents thorough heating and imperfect transformation of the metal.

71. Time of Soaking.—Complete refinement of grain and mutual absorption of metallic constituents at elevated temperatures require time, hence the need of holding (soaking) the parts or load at an elevated temperature. *Too long a period of soaking promotes grain growth,* so that the desirable compromise requires an account of the mass and shape of the object being heat-treated.

An excellent rule for circular shapes of steel is to soak for half an hour above the upper critical temperature for every 0.2 sq. in. of cross-sectional area. Parts with sharp edges, for example, a square bar, require slightly less time of soaking if the heating has been uniformly and gradually applied because of the great heat absorption at the edges. Incidently, there is a tendency to grain growth at these edges.

Table V gives the approximate time of soaking 17S and 24S aluminum alloys at heat-treatment temperature.

72. Cooling Rates.—Retention of the desirable combination of hard, strong, and tough qualities of metal at room temperatures requires rapid quenching from the heat-treating temperature. *Cold water is the recommended medium for cooling aluminum alloys rapidly enough to give the metal the proper quality of corrosion resistance.* Transfer of the load from furnace to quenching tank should be held to a minimum of a few seconds. *Partial immersion* does *not* produce satisfactory results.

Full mechanical properties of steel are obtained immediately after the quenching.

The aluminum alloys of the *natural aging* variety require *four days* at room temperature to attain full hardness, strength, and toughness. Care must be exercised *never to reheat these alloys to above* 212°F., if full mechanical properties are to be preserved after the proper quenching.

73. Aging.—It should be noted that temperatures below room temperature will temporarily retard normal age-hardening of duralumin whereas extreme cold, such as may be obtained with dry ice, actually arrests aging. Aging is resumed upon return to room temperature.

74. Temperature Control.—Accurate temperature-measuring equipment is necessary in heat treatment. *Calibration* at frequent intervals (once a month) to determine the errors in temperature-measuring equipment should be a matter of regular inspection, if success in heat treatment is desired. When the errors are known, the corrections can be made with assurance of the accuracy of the temperature reading. Methods of calibrating this equipment may be obtained from the manufacturer.

75. Effects of Composition.—The alteration in critical temperature with carbon content (see Fig. 47*a*) necessitates a different elevated temperature for each alloy.

The full mechanical properties of aluminum alloys are attained immediately after quenching when the *magnesium* and *silicon contents* are high.

The aluminum alloys used for structural parts in aircraft are those that can be heat-treated to produce high strengths. When finally installed in the airplane, such materials must be in the heat-treated condition.

When *duralumin* or *copper aluminum alloy* is heat-treated, a period of four days after quenching is required for aging to develop the optimum mechanical properties. For other aluminum alloys of casting and the forging type for propellers and engine pistons, precipitation treatment is required to develop mechanical properties. The principal alloys of this group, used in aircraft, appear in Table VI.

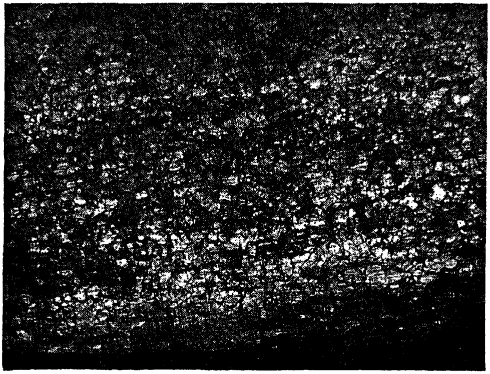


FIG. 50.—Surface of overheated steel.

The principal aluminum alloy used in aircraft structures is called 24S by the Aluminum Company of America. An improved alloy of the duralumin type, it contains the same alloyed elements as the earlier 17S, but in different proportions and possesses greater strength.

Because of the limited range in which heat treatment of aluminum alloys must be performed, it is usually difficult to determine this range by test. It is recommended that this information be obtained from the original manufacturer of the aircraft.

Classification.—Aluminum alloys are obtainable in either *cast* or *wrought* forms, by wrought being meant there is mechanical working. They may be further classified as nonheat-treatable and heat-treatable alloys. The chemical composition of alloys is indicated by the alloy number. Wrought alloys are distinguished from cast alloys by the letter "S" following this number.

An alloy, fully heat-treated and of *age temper* (such as 24ST), may be further *cold-worked,* as by rolling, to obtain still higher strengths. It is then said to be in the "RT" temper. Although this further rolling reduces the elongation and workability, 24S and Alclad 24S in the RT temper are regularly corrugated and formed into other aircraft parts. The various cold-worked and heat-treated tempers are also indicated by symbols shown in Table VI.

The mechanical-properties specifications for wrought alloys and products and for cast alloys are given in Table IV.

Sheet.—For the outer coverings, or skin, and various other structural parts of a modern airplane, a large percentage of the material used is aluminum-alloy sheet.

Owing to the high stresses in some flight conditions, the *higher yield point strength* of alloy 24ST is almost universally used in preference to 17ST.

Nonstructural parts are sometimes made from alloys that are not heat-treated or from heat-treated alloys of lower strength.

Whether the sheet is 24S or 17S, it is usually supplied as Alclad sheet. This alloy has a high-strength sheet, covered on each side with a coat of high-purity aluminum, with attendant high resistance to corrosion. This coating is rolled into the surface and prevents corrosion at cut edges or torn surfaces near rivet heads.

Increased use of 24S and 17S coil strip has been found to have economical and other advantages. Heat-treated coiled strip is generally used in fabricated rolled sections, where long lengths are useful. Annealed coiled strip is used for blanking out small parts which are subsequently heat-treated.

Extruded Shapes.—An extruded shape is produced by forcing hot metal through a die in which the opening corresponds to the shape of the desired cross section. The process permits production of many shapes that cannot be rolled economically.

TABLE VI.—CLASSIFICATION OF ALUMINUM ALLOYS

Alloy	Class	Tempers	Composition, % by weight*					Solution temperature for heat treatment, °F	Precipitation heat treatment		Typical aircraft uses
			Cu	Mn	Mg	Si	Others		Temperature, °F	Time of aging	
Heat-treatable											
17S	Wrought	O T	4.0	0.5	0.5	0.3		930–950	Room	4 days	Hydraulic lines, structural fittings, machine fittings
24S	Wrought	O R T	4.5	0.6	1.5			910–930	Room	4 days	Structural, struts, castings, fittings
25S	Wrought	T	4.5	0.8	0.8	0.8		960–980†	325	4 days	Propellers, engine parts
32S	Wrought	T	0.9		1.0	0.125	0.9 Ni	930–950	325	4 days	Pistons
A51S	Wrought	T			0.6	1.0	0.25 Cr	960–980‡	325	4 days	Fittings, engine parts
53S	Wrought	O W‖ T			1.3	0.7	0.25 Cr	960–980‡	315–325 or 345–355	18 hr. 8 hr.	Fairings, electrical conduit, semistructural
61S	Wrought	O W‖ T	0.25		1.0	0.6	0.25 Cr	960–980§	315–325 or 345–355	18 hr. 8 hr.	Engine baffles, fairings
195	Cast	T4 T6	4.0					960–980§	325	4 days	Structural parts
220	Cast	T4			10.0			910–930	Quench		High-strength structural fittings
Nonheat-treatable											
2S	Wrought	O ½H, ¾H H					*				Tanks, nonstructural
3S	Wrought	O ½H, ¾H H		1.2							Tanks, nonstructural
43	Cast	As cast				5.0					Tank fittings
52S	Wrought	O ¼H, ½H ¾H, H			2.5		0.25 Cr				Tanks, fairings, oil fuel instrument lines

* Balance of composition is aluminum.

† To obtain full mechanical properties of this alloy requires precipitation treatment at 285 to 295°F. for 12 hr.

‡ To obtain full mechanical properties of this alloy requires precipitation treatment at 315 to 325°F. for 18 hr.

§ Hold at heat-treating temperature depending on size and shape.

‖ W temper applies only to alloys requiring artificial aging to attain T condition.

Courtesy of Aluminum Company of America.

Extruded shapes are used as stringers and important structural parts of the airframe and engine cowling. Extrusions of 24ST are the most common. Extruded shapes not demanding high strength are often made from 53S or 61S in a *suitable temper*, or from 2S or 3S. Certain restrictions of U. S. Army specifications permit spot welding of bare extrusions of the above alloys under limited conditions.

Forgings.—Forgings serve most important functions as structural and other fittings in addition to their well-known uses for making engine crankcases, pistons, and propeller blades. Many forgings are made from alloy A51ST, while 14ST is commonly used for highly stressed forged fittings. Other alloys in common use for forgings are 17S, 18S, 25S, 32S, 53S, and 70S.

Castings.—A large part of the airframe itself is composed of aluminum castings that are produced by one of three basic methods—sand, permanent mold, and die. Permanent-mold castings are used in order to obtain better service, more accurate dimensions, and higher mechanical properties.

Die castings are restricted to parts subject to large production, which distributes the die cost over a large number of units, at the same time reducing machining costs, because of better finish and closer tolerances.

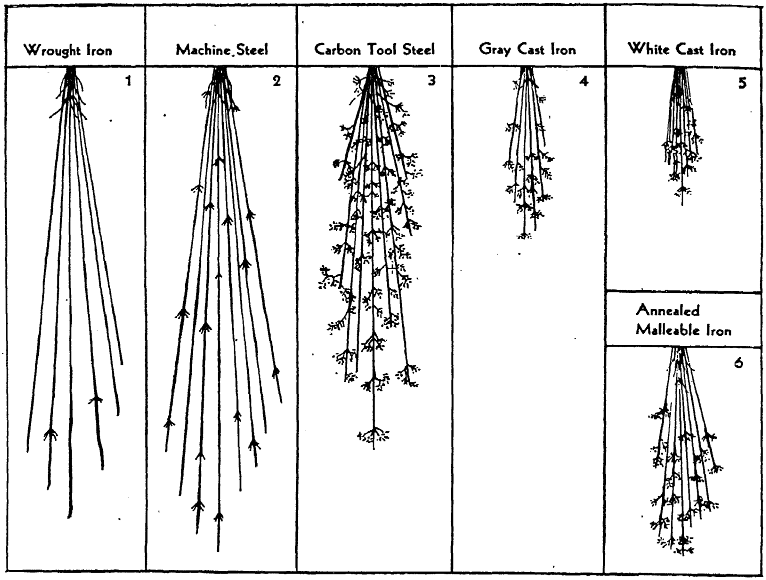
Castings may readily be used to replace forgings of complicated shape. While forgings are sometimes preferred because of their greater strength and uniformity, castings may be usefully substituted for forgings. It is to be noted that many castings are furnished "as cast," and other alloys are heat-treated to obtain increased strength. For this reason, any replacement in this structure must take account of the condition of the casting before any replacement can be made.

76. Simple Tests for Identifying Metals.—Many times in repair, when specifications of metals used in the structure are

TABLE VII.—DENSITY OF AIRCRAFT METALS

Metals	Density, Pounds per Cubic Inch
Aluminum alloys	0.096 to 0.101
Steel	0.283
Brass	0.314
Bronze	0.315
Monel	0.321
Copper	0.323

Table VIII.—Simple Tests



Line	Metal	Volume of stream	Length of stream, in.†
1	Wrought iron	Large	65
2	Machine steel	Large	70
3	Carbon tool steel	Moderately large	55
4	Gray cast iron	Small	25
5	White cast iron	Very small	20
6	Annealed malleable iron	Moderate	30
7	High-speed steel	Small	60
8	Manganese steel	Moderately large	45
9	Stainless steel	Moderate	50
10	Tungsten-chromium die steel	Small	35
11	Nitrided nitralloy	Large (curved)	55
12	Stellite	Very small‖	10
13	Cemented tungsten carbide	Extremely small	2
14	Nickel	Very small‖	10
15	Copper, brass, aluminum	None	. .

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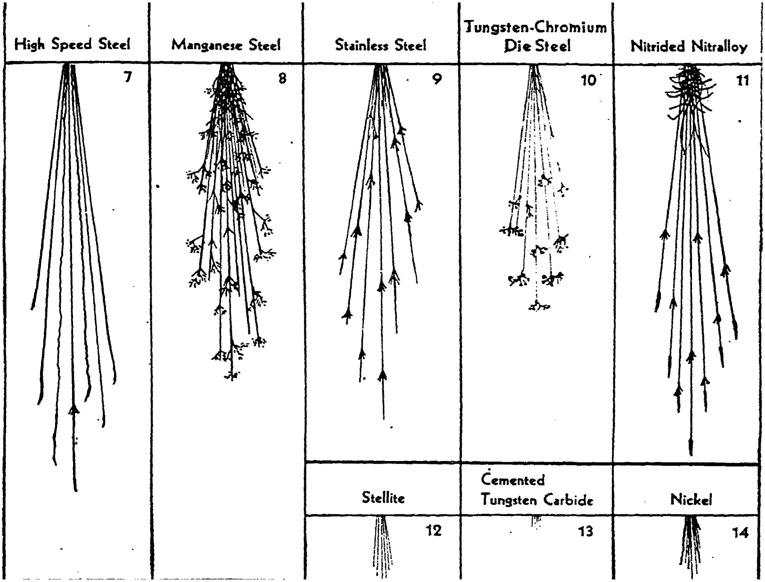
* *From Metals Progress*, October, 1940, p. 386*A*.
† Figures are obtained with 12-in. wheel on bench stand and are relative only. Actual
‡ Spurts are the sparks (seemingly small explosions) that occur at intervals on the carrier
§ Spurts are blue white.
‖ Some wavy streaks may be observed.

for Identifying Metals*



Color of stream		Quantity of spurts‡	Nature of spurts‡	Line
Close to wheel	Near end			
Straw	White	Very few	Forked	1
White	White	Few	Forked	2
White	White	Very many	Fine, repeating	3
Red	Straw	Many	Fine, repeating	4
Red	Straw	Few	Fine, repeating	5
Red	Straw	Many	Fine, repeating	6
Red	Straw	Extremely few	Forked	7
White	White	Many	Fine, repeating	8
Straw	White	Moderate	Forked	9
Red	Straw§	Many	Fine, repeating§	10
White	White	Moderate	Forked	11
Orange	Orange	None		12
Light orange	Light orange	None		13
Orange	Orange	None		14
. . . .	. . . .	None		15

length in each instance will vary with grinding wheel and pressure.
lines.

not available, it becomes necessary to resort to simple tests for identifying the more prevalent metals. The following procedure, requiring no metallurgical training, is useful in this identification:

The best procedure is to *mark each kind of metal* upon receipt, S. A. E., Navy, or Army designation in accordance with the specification (Table III).

If the *weight of the metal* can be accurately measured, a rough classification can be made by comparing the weight per cubic inch with the density in Table VII.

It should be kept in mind that *weight alone* is not an absolute criterion for classification because there are many kinds of steel used in aircraft, which vary little in density and furnish no means of distinction on this basis. Again, appearance of aluminum-copper alloys and Monel metal or aluminum alloys depends upon their cleanliness and the vagaries of color blindness (see Table VIII). Similarly the *spark test* cannot be relied upon as a sole means of distinguishing metals since all metals, principally aluminum, and copper alloys, do not exhibit sparks.

The *blowpipe* or *torch test* requires much experience to judge unfailingly the kind of metal in hand.

Since the metals for aircraft use respond differently to each test for the determination of the kind of metal, it becomes possible by subjecting the metal to each test—appearance, chip, spark, and blowpipe—to approximate the type of metal in question. All of the tests indicated in Tables VII and VIII should be made before making a decision. One, two, or even three of the tests may not be reliable.

77. Detection of Metal Defects.—There are three aids to reliable inspection of metals for defects: (1) X-rays, (2) Magnaflux, and (3) microscopic examination.

1. *X-rays* require a suitable tube for projection of the X-ray beam against the part under inspection, and a transformer with voltage regulation equipment. Until recently the X-ray units have been stationary installations, and the parts, particularly assembled structures, had to be taken to the units in specially built lead-lined rooms. *X-ray sets now are made available as portable equipment which may be taken to the point of inspection.*

Operation of this equipment is attended by a shock hazard due to high voltages required and by a deleterious effect of long exposure of the body to X-rays. Manipulation of this highly specialized equipment must remain in the province of trained X-ray technologists.

With the proper interpretation, the X-ray photographs of aircraft reveal important data. *The X-ray method has the advantage that it preserves the usefulness of the part or structure exposed to the X-rays.*

Development of the X-ray film requires a special experience. Improper handling of the X-ray film may not reveal existing defects, or imperfections in the film may readily indicate a defect where it is nonexistent. When skilled operators handle the X-ray equipment and examine the photographs, the results are reliable.

Imperfections, such as hairlines, which lower the fatigue resistance of the metal, are detected in forgings less than 2 in. thick.

2. *Magnaflux* is the term used to define the patented nondestructive method of magnetizing metal parts which are suitably covered with a paramagnetic material, usually finely divided iron particles. If a defect, such as an internal crack, exists in a position askew of the direction of the magnetic field, the magnetized powder collects over the defect. It is theoretically and actually true that *a defect, which is parallel to the flux, is not indicated.* As the angularity of the defect relative to the flux path is increased, from a parallel to a 90-deg. position, the presence of the defect is more pronounced. It is necessary to demagnetize after each inspection, since cross-magnetic fields neutralize or diminish the effective indication of the magnetic powder.

Defects, such as seams in steel products, cracks resulting from quenching, grinding, fatigue, or welding are readily distinguished when aligned across the magnetizing field. An example of a defect in a master rod is shown in Fig. 51.

The *Magnaflux process* is fully covered by patents and requires appropriate licensing for commercial use. Two methods are available, one using the direct-current method of magnetization which requires more than 300 amp. The latter type of unit makes possible the inspection of parts with large bulk, such as crankshafts. *The process is used both on magnetic metals, such as steels, and nonmagnetic metals, such as aluminum alloys.*

The *dry powder* used is a finely divided iron powder of high purity. The part is covered with a coating of this powder to improve the magnetic permeability so that the maximum amount of powder will collect at the defect. Color, which is added in this coating, improves the visibility. The powder is applied by dusting it on the part. The excess powder is then dispersed by tapping, jarring, or tilting the part. *The part under inspection must be thoroughly cleaned and free of oil or grease to eliminate any possibility of the powder's adhering at the dirty areas and covering defects.* Parts which have been subjected to this treatment should be slushed with oil to prevent corrosion of the surface which was chemically cleaned.

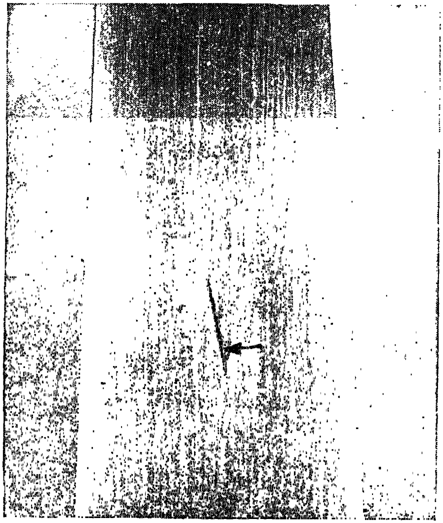


Fig. 51.—Magnaflux record of master-connecting-rod defect. Dry powder used. (*Courtesy of Metals and Alloys.*)

In the *wet method* of Magnaflux inspection a magnetic oxide of flow consistency is used as a suspension in "varsol," a vehicle similar to kerosene. Dispersion of the magnetic oxide and the kerosene, when the part is immersed, is usually obtained by bubbling air through the solution.

The wet method is preferred because cleaning of the part or parts is unnecessary and the paramagnetic oxide adheres to minute cracks much less in dimension than is possible to detect with dry powder. The large cracks cannot be wiped clean of the oxide, since this material filters into the crack leaving a black line. With dry powder the deeper cracks show a greater accumulation of powder, which resists dislodgment by blowing or jarring. Experience is requisite to estimating the extent of the defect. Dry powder has a distinct advantage for rough surfaces such as forgings and welds. But the wet method clearly has the advantage for finished surfaces. An example of this is illustrated in Fig. 52, which shows a crankpin defect.

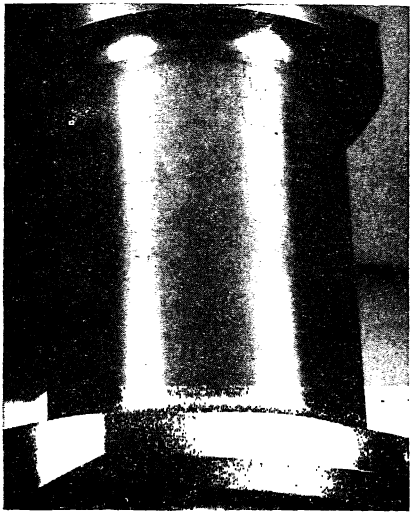


FIG. 52.—Defects in crankpin revealed by Magnaflux. (*Courtesy of Metals and Alloys.*)

3. *Microscopic inspection* involves the sectioning of the part where the defect is anticipated, therefore the part is destroyed, so that its further use is impossible. *This method is the only method of determining the character of the defect,* whether there is porosity or a crack due to overloading (whatever the cause), or whether there is an impurity or a defect due to the nature of the crystalline structure.

There are two means employed to reveal the defects by the microscopic method:

1. The macrotest.
2. The microtest.

In the *macrotest* the sectioned part is ground and then polished to eliminate the grinding cracks. The usual treatment thereafter is to boil the part at 180°F. in a concentrated solution consisting of 80 per cent concentrated sulphuric acid (H_2SO_4) and 20 per cent hydrochloric acid (HCL). The time of immersion required is about 45 min. The part collects a soot owing to oxidation of the metal by the acid, which may be removed by a hot-water rinse. After drying, the specimen may be examined under the microscope. *Forged parts or parts severely cold-worked respond readily to this treatment*, revealing cross fiber and inherent weakness in fatigue. Figure 53 shows a serious cross-grain structure in a rivet which has been headed while hot. The fiber orientation is clearly visible as magnified 4½ times actual size. Figure 54 shows an example for cold-worked bolts. The picture shows the progressive development of the metal flow during the different stages of cold-forming. At the right may be seen a crack in the head of the bolt, caused by overstressing.

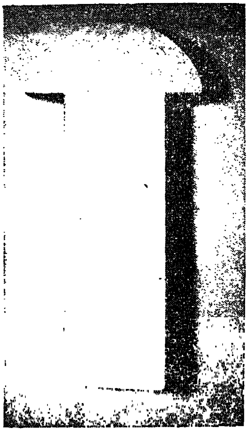


FIG. 53.—Defective hot-formed rivet head.

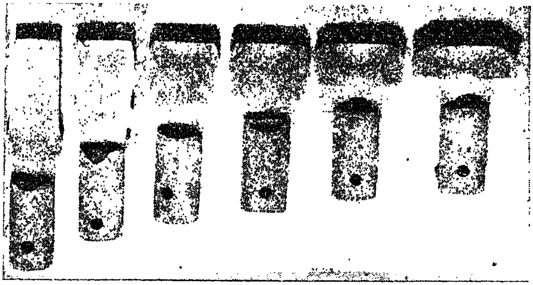


FIG. 54.—Progressive cold forming of bolt. Note defect in rim of head by overstressing in die.

For the *microtest* the specimen is sectioned and progressively ground to a flat surface on a belt emery grinder with grain size varying from 60 to 320. Following this, the grinding is continued by hand, using successively 0, 00, 000, and 0000 emery paper, and applying a minimum of pressure to prevent the deepening of cracks. The grinding preparation of the specimen for the etching solution is completed by polishing the specimen on flat cloth-covered wheels until a mirrorlike surface is obtained. The specimen is now rinsed with alcohol. The alcohol is then slushed off by water, to prevent staining, and the specimen is dried.

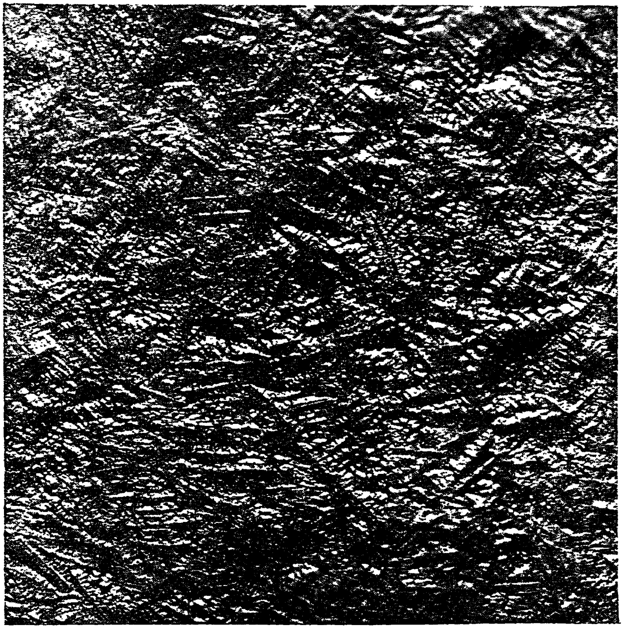


FIG. 55.—Dendritic structure of cast-aluminum alloy. Magnification 2.5 ×; unetched.

Each metal has its own best etching reagent which reveals its grain under the microscope. For steel, an immersion of approximately 5 sec. in an alcoholic solution of 5 per cent nitric acid is universally satisfactory. The traces of acid are then removed with alcohol and water, and then the specimen is dried. It is now ready for a microscopic examination under a microscope of magnifying power in excess of 20 times.

In etching aluminum alloys, in preparation for a microscopic examination, aqueous solutions—those having the acid or alkali suspended in water—are best. Table IX shows satisfactory aqueous solutions and time of immersion in each.

The dendritic structure of the aluminum alloys appears in Fig. 55. Figure 56 is a macrograph showing flow lines in a bolt and in a rivet.

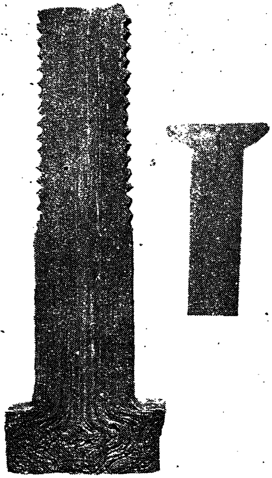


FIG. 56.—Macrograph showing flow lines in a bolt and in a rivet.

78. Mechanical Failures in Aircraft Parts.—Any aircraft part, because of its highly stressed condition, is very sensitive to surface imperfections. Failure usually starts in the tension areas.

When the cause of failure can be traced, the remedy can be applied correctly. The causes of failure may be summarized as due to (1) poor workmanship, (2) faulty heat-treatment practice, or (3) improper distribution of metal.

Poor workmanship includes poor judgment in the use of metals in repairs. A knowledge of the kinds of materials and the safe allowable load of each is necessary for reliable workmanship.

Use of excessive pressures, which is a natural tendency in riveting, damages both the rivet and the plates. Squeezers and hydraulic presses, now in use, supply more than ample pressure for most rivets. Care must be exercised, therefore, in using just sufficient

TABLE IX.—SOLUTIONS FOR ETCHING ALUMINUM ALLOYS

Aqueous Solution	Immersion Time—Condition
0.5% hydrofluoric acid (HF)	15 sec., cold
1% caustic soda (NaOH)	10 sec., cold
0.5% hydrofluoric acid (HF) 2.5% hydrochloric acid (HCL) 1.5% nitric acid (HNO_3)	15 sec., cold
20% sulphuric acid (H_2SO_4)	30 sec., 70°C.
25% nitric acid (HNO_3)	40 sec., 70°C.
10% caustic soda (NaOH)	5 sec., 70°C.
10% hydrogen peroxide (H_2O_3) 10% sodium chloride (NaCL)	10 sec., cold

pressure to upset the rivet. Excessive pressure countersinks the plate area under the rivet heads, making an area vulnerable to fracture. See Fig. 57 for an example of a countersunk area and the reduction in the effective-load area in the sheet under the rivet. *Use of dull machine tools such as milling cutters, drills, and punches is bad practice as they tear the metal and reduce the fatigue of highly stressed parts.* Presence of tool marks on finished parts or serrations from heavy-grinding practice hastens the failure of the parts, perhaps at a very critical moment.

Meticulous care must be exercised in handling parts if the full life of a part is to be realized. For example, parts clamped in hard vise jaws should be protected by copper or aluminum facings.

Evidence of *rapid and uneven heating* appears as a distortion; and overheating of metal parts causes distortions and warpage. These conditions cause difficulty in alignment of assembled units and in straightening. The usual methods, which require more thought than is usually employed, are to correct the misalignment with the power presses or hammers. The inaccuracies of this straightening process overstress a steel which possesses a low ductility in the heat-treated condition. An instance of the fractured push rod on No. 1 exhaust of a radial aircraft engine, and the subsequent destruction of the engine and plane, serve to remind the mechanic that *straightening of steel after its heat treatment is a very poor practice.*

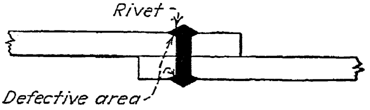


FIG. 57.—Effect of excessive upsetting pressure.

Aluminum alloys differ from steel in the respect that for a few minutes immediately after heat treatment they remain plastic, so that straightening may be done without danger of overstress.

Warpage often occurs with temperatures in excess of those required for that metal, since the shrinkage is the contraction per degree of temperature. The higher temperature produces greater total contraction than otherwise should occur.

The most common results of excessive temperature during heat treatment are coarse grain and burned intercrystalline areas. (The poor fatigue resistance of coarse-grained metal is outlined in Par. 65.)

The most severe effect of overheating, that of burned metal, is least susceptible to detection by external examination. The photomacrograph in Fig. 58 indicates the deterioration of duralumin grains which have been subjected to excessive temperature. In this duralumin may be seen the oxidation of the aluminum mass which has been coarsened by a high temperature, and the fused intercrystalline area which has been embrittled. The depreciation of the greater strength in the intercrystalline area constitutes vitiation of the strongest part of the metal (see Par. 65). Retrieving of the properties of metal in this condition can be obtained only by remelting in the presence of a suitable flux.

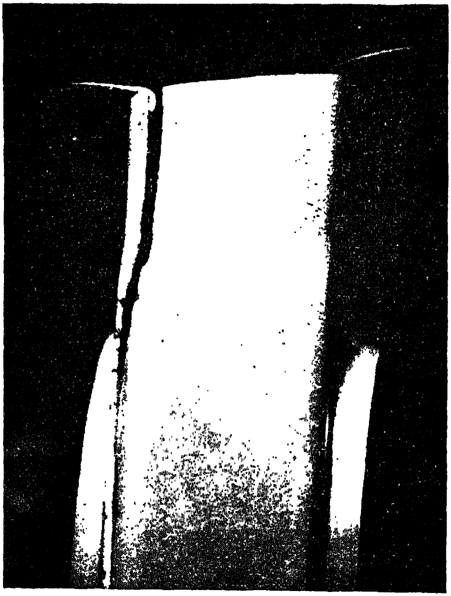


FIG. 58.—Overheated duralumin in bulkhead fitting. Note blistered appearance, color change, and brittle fracture in overheated section. Compare tough fracture in correctly heated sections.

Overheating in steel produces microchanges, such as coarsened grain and fusion of intercrystalline areas comparable to those of aluminum alloys. The only difference is the burning of the carbon from the iron, called *decarburization.* All of these effects are shown in Fig. 50. The weakened surfaces of this steel specimen are obvious.

Aluminum alloys often exhibit exterior evidences of overheating more clearly than other aircraft metals. Figure 58 is presented as an example which shows three notable evidences of excessive heating. These are (1) the change in surface color accompanying severe cases, (2) a mottled-appearing surface, and (3) a brittle fracture in the overheated area. The latter condition is readily discernible when a straight-edged fracture in the overheated area is compared with the jagged, tough-appearing fracture of the sound metal in the break farthest from the end.

Overheating is minimized by using temperature-measuring equipment for which the errors in temperature are known. When aircraft parts are held within the specified temperatures for the particular alloy, the correct results are obtainable.

After heating the metals to heat-treatment temperatures, it is necessary to quench the specimen quickly and correctly to obtain full mechanical properties without warpage. Projection of parts into the quenching bath obliqued in such a manner as to develop vapor pockets at any point on the surface promotes warpage and soft spots.

Transfer of heat through the vapor of a liquid is slower than when the liquid completely "wets" the surfaces. Distortion develops in the vapor areas when the hot part finally cools. Relief of the shrinkage stress in these areas is by warpage, or, in very severe instances, by surface cracks which are termed "quenching cracks." The remedy for these difficulties may be found in the quenching technic.

Agitation of the cooling solution around the specimen during immersion serves to break up the vapor. Complete submersion of the specimen is required to prevent uneven cooling. Movement of the part being quenched should be in such a direction as to favor the minimum collection of vapor on any part of specimen.

Improper distribution of metal is often a source of weakness. This is found in cast and fabricated parts of an aircraft structure and particularly in welded structures.

Frequently, excessive heat in welding produces *undercutting* at or near the weld bead which leaves less cross section than the original sheet or tube. The undercut areas become vulnerable to fatigue or highly concentrated stress. Failure of a fitting originating in an undercut weld is shown in Fig. 59.

Equally as dangerous as undercutting is the excessive reinforcement of a weld bead. The sudden increase in stiffness and strength in the reinforced area affects the transfer of the highly intensified stress to the adjoining plate metal. The movement of the welded joint, due to contraction after cooling, is greatest in the bead. The bead, however, is of ample proportions to absorb the shrinkage, whereas the plate metal is not. If cooling cracks do not develop, the deposited metal and its adjoining plate metal are left under high shrinkage stress. The bead proportions for weld metal are established in accordance with the standards shown in Fig. 82 and represent the compromise between the extremes outlined on page 97.

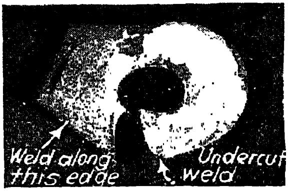


FIG. 59.—Fatigue failure of fitting originating in undercut weld. Final fracture hastened by overloading.

JOB UNITS

Job Unit 3. Cadmium Plating

Object: To plate metallic cadmium on a steel aircraft bolt.

Equipment: 1. Direct-current generator with capacity of 15 volts and 59 amp. Eclipse Aviation Generator Model 2144 at 2,400 to 3,000 r.p.m. is satisfactory.

2. Four cleansing tanks: The first, with provisions for 20 per cent solution of caustic soda (NaOH) or electro cleaner; the second, hot- and cold-water rinse; the third, both of 10 per cent solution of hydrochloric acid (HCL) or commercial nitric acid; and the fourth, a weak cyanide dip (2 oz. NaCN per gallon of water).

3. Electroplating tank: A glass, wood, or steel tank with negative-conductor bar at the center from which fittings or bolts are suspended in the electrolyte, and two positive-conductor bars (brass, ½ in. in diameter) for suspending the cadmium bars for plating. These bars or rods are spaced at intervals of 3 in.

4. Three gallons of a solution (or sufficient to immerse the cadmium and parts to be plated) consisting of the following compounds, in the designated quantity per gallon of water:

Sodium cyanide	7 oz.
Cadmium oxide	3 oz.
Caustic soda	1 oz.

(CAUTION: This solution and the lethal gas which would be generated by introducing muriatic acid are deadly poison and should be kept away from the mouth, cuts, lungs, etc.)

Procedure

1. Preparation for plating: First clean the part to be plated. That is, remove all scale, flux, etc., caused by welding, by buffing with a wire brush, and then polish the part with emery cloth to produce a clean, smooth surface. This procedure leaves the part only mechanically clean.

The part must be chemically clean for electroplating and this is accomplished as follows (see the procedure outlined in Fig. 60):

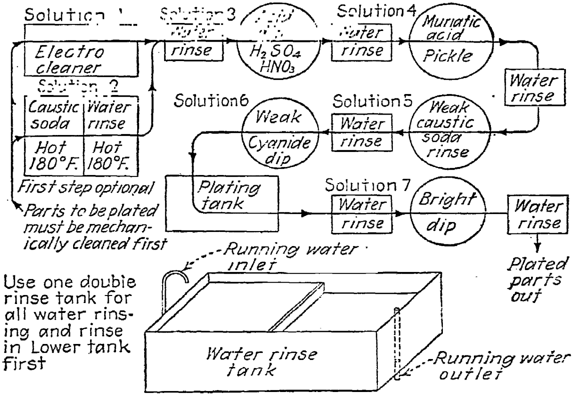


FIG 60.—Plating cycle.

Place the part in boiling caustic soda or electrocleaning bath for 5 min. to remove grease, then in hot and cold water to remove alkali. The part is next immersed for 1 to 2 min. in a 10 per cent solution of hydrochloric acid (HCL) or muriatic acid, after which it should be thoroughly rinsed in hot water to remove any trace of acid. The sodium cyanide in the plating tank generates a deadly lethal gas for which the antidote is of doubtful value, unless used instantly.

2. Turn on the current in the plating before the parts are immersed. This prevents the "scum" on the top of the tank from contaminating the chemically cleaned surface. Care must be exercised to prevent the surface to be plated from being touched or handled after it leaves the muriatic acid or cyanide-dip rinse.

3. Attach the part by a wire suitable for suspension from the cathode (negative terminal) or contact rod so that the part touches neither the tank sides nor cadmium anodes. The apparatus which is used (Fig. 61) should permit the voltages to vary from 1½ to 5 volts and the amperage

from 10 to 30 amp. per square foot of the part. In calculating the surface area of the part it should be remembered that all sides must be plated. for which allowance must be made. For example, two sides must be included in the area calculations.

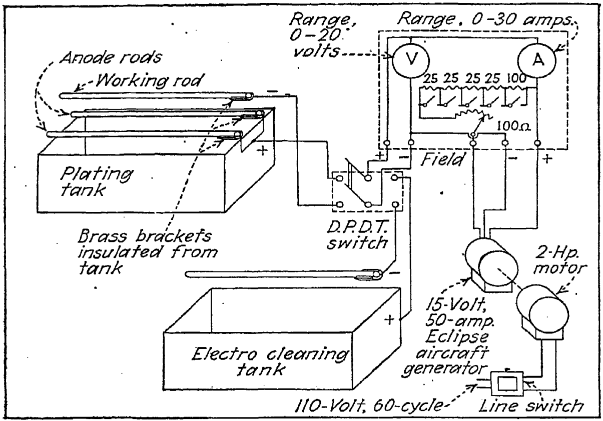


FIG. 61.—Wiring diagram—cadmium plating.

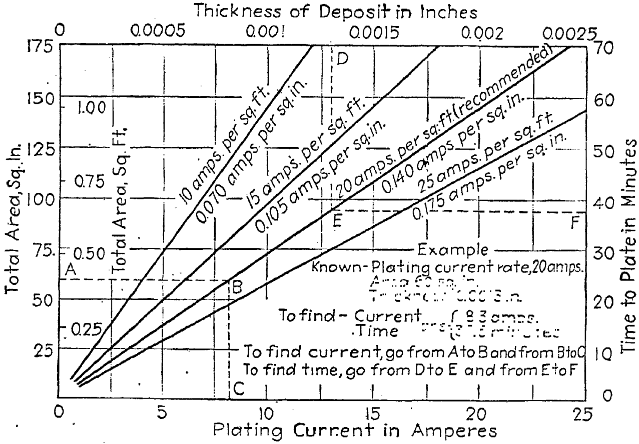


FIG. 62.—Current and time curves for cadmium plating.

The rate of plating is measured in terms of the amount of current, in amperes, used per square foot of area. An average rate is 20 amp. A difference in area of two parts being plated simultaneously will make a difference in the plating rate used, as more current is required for the large part than for the small part. With experience the plating rate is approximated by observing the solution of gas from the cadmium cathodes. For more exact information, the chart (Fig. 62) enables the operator to calculate the correct rate:

4. After enough metal is deposited, cut off the current and leave the part in the plating bath for a while to help "fix" the cadmium plating.

5. The part is ready to be moved from the bath at the end of the time when the plated cadmium is from 0.001 to 0.002 in. in thickness per surface. After removal from the bath the part should be rinsed in hot water, dried and assembled for service.

Questions:

1. Find the plating area of a flat plate 2 in. square and $\frac{1}{8}$ in. thick.
2. Determine the correct plating rate for the flat plate in question 1.
3. Describe the plating process for this flat sheet.

Job Unit 4. Effect of Heat on Steels

Object: To observe the effect of various degrees of temperature on the hardness, strength, and grain size (structure) of high-carbon steel.

Material: A test bar Fig. 63 of high-carbon steel (0.85 to 0.95 per cent carbon).

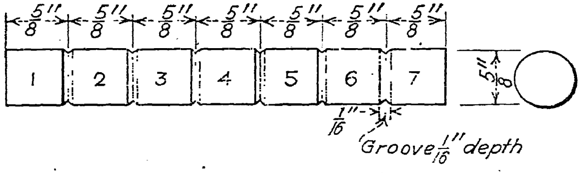


FIG. 63.—Impact specimen.

Apparatus: A scleroscope or Rockwell hardness tester, a gas furnace, and a microscope.

Procedure

1. Heat furnace up to about 1600°F.

2. In the meantime, test the hardness of various sections of the test bar, which should be about the same for all sections. Record the result.

3. Insert the end of the test bar, marked 1, into the furnace in such a way that the rest of the bar will be heated by conduction; that is, so there will be a gradual variation in temperature along the bar, until the lowest temperature at 7, Fig. 63, is 900°F. As soon as *section* 1 or the hottest end has reached about the same temperature as the furnace (about 1600°F.) remove bar from furnace and quench quickly in water, immersing *section* 1 first.

4. Dry the bar and polish off the scale with a piece of emery cloth.

5. Test the hardness of each section with the Rockwell tester. Record the hardness of each section.

6. Observe while breaking off the pieces:

a. The relative intensity of the blow required to break off each section.

b. The coarseness of the grain (whether coarse or fine). Examine with eye or the microscope.

c. The type of fracture (whether coarse or fine). Examine with eye or microscope.

d. The relative hardness of each section as determined by using a file or a Rockwell tester.

Discussion

1. What can you say as to the relationship between the relative hardness, grain size, ease of fracture, and temperature of each section; that is, how do the hardness, grain size, and ease of fracture of the section which reached the highest temperature compare with those sections which were heated to a lower temperature? Check your findings with the correct heat treatment in Fig. 47*a*.

2. What, then, would you say is necessary to harden tool steel or high-carbon steel?

3. Does this experience show exactly to what temperature a piece of tool steel should be heated in order to produce the most desirable combination of hardness, strength, and grain size? Why?

The determinations of this experiment are only fair approximations, but they actually show what happens when steel is quickly cooled from various temperatures.

Job Unit 5. Identification of Aluminum Alloys

Object: 1. To become acquainted with aluminum and its alloys by a study of its appearance.

2. To practice distinguishing the heat-treated and not heat-treated alloys.

Materials: Selection of aluminum fittings for aircraft, anodic-treated stringers, Alclad tube, propeller blade, engine piston, pressed-aluminum sheet, all of which have been designated by suitable numbers.

Procedure

1. List from this group of specimens the heat-treated parts.

2. List the specimens not heat-treated.

3. Record by number the parts formed by cold-working and by hot-working.

4. State the evidences of overheated duralumin, if present.

Questions

1. Prescribe the correct heat treatment of duralumin to obtain the maximum physical properties and resistance to corrosion.

2. How are hot-worked specimens designated in specifications? (Ref. 5.)

3. For cold-forming by drawing sheet 24SO, 1/16 in. thickness, what is the minimum bend radius? What would be the result of forming an overheated 24ST fitting?

4. In what way may heat treatment be done to assist the corrosion resistance of aluminum alloys? (Ref. 5.)

Report: Write the results of your investigation in the form of a report which gives all the information you obtained in such a way that others will understand all the details.

Review Questions

1. Describe the method of transforming a hard steel into a softened state.

2. *a.* What is stress-relief anneal?
   b. How does tempering differ from stress-relief anneal?

3. What are the advantages of normalizing compared to full annealing?

4. *a.* What method is used to harden high-carbon steel?
   b. How is it possible to harden the surface of a low-carbon steel?

5. What is nitriding? For what steel is it used?

6. Name two advantages of a nitrided steel in comparison with carburized steel.

7. For what metal is anodic treatment used? Why is this process required?

8. *a.* In what four ways are the results of heat treatment affected?
   b. Illustrate how one of these factors changes the heat treatment.

9. *a.* When cooling a piece of heated steel to room temperature, it has been stated that, in shrinking, the hot side becomes the short side. Indicate by an illustration of a flat bar how the piece will warp when taken from the furnace and placed upon a cold steel plate to cool.
   b. How would you prevent this warpage?

10. Name the most common causes of failure in aircraft construction.

11. To what cause would you assign the failure of a steel drill which dulls rapidly when drilling hardened tool steel?

12. Describe the solution treatment for 24ST alloy.

13. *a.* What is the precipitation heat treatment and for what alloys is it used?
   b. Why should the precipitation heat treatment be used on certain alloys?

14. Describe a method whereby overheated aluminum alloys may be detected.

15. What constitutes the best method of reclaiming burned steel or aluminum.

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Question for Thought and Study of References

1. State the temper designations for aluminum alloys. (Ref. 5.)

2. What is the significance of the term "endurance limit"? (Ref. 3.)

3. Name important mechanical defects in mechanically worked metals. (Ref. 7 and 8.)

4. What are the effects of heat upon cold-drawn structural shapes? (Ref. 8.)

5. In what orientation does fatigue cracking of duralumin occur? (Ref. 6.)

6. Name a few of the "stress raisers" which decrease the fatigue life of metals. (Ref. 11.)

7. Describe the procedure in balancing a metal propeller. (Ref. 11.)

8. Describe how metals are tested in fatigue. (Ref. 7.)

9. Name some of the uses of anodic treatment of aluminum for aircraft. (Ref. 12.)

10. What factors should be studied in the developing of a design for a stamped or formed steel part? (Ref. 13.)

CHAPTER VII

AIRCRAFT-MAINTENANCE WELDING

It is essential that the airplane mechanic be a skillful welder because, in making repairs on an airplane structure, welding is the most satisfactory method yet devised, from the standpoint of *low cost*, *minimum time*, and *weight*.

Requirements for the Airplane Welder.—An apprentice welder must have completed grade school and junior high school or their equivalent in order to advance in his trade. To practice the trade as a journeyman welder, the student must complete the qualifying tests prescribed by the *Bureau of Air Commerce*. All welded repairs must conform with the regulations prescribed in *Aeronautics Bulletin 7-H* for aircraft with commercial licenses.

Physical.—The minimum age limit is 16 years. The student must pass the regulation physical examination of eyes, ears, nose, lungs, heart, and abdomen. The aircraft welder must be of sound mind and body and be physically fit to withstand the usual hazards of the welding trade.

Mental.—The welder must be familiar with the correct welding procedure for the various types of weld repairs in order to make sound welds. Only the best welds should be allowed in a repaired section.

79. Equipment and Materials for a Welding Shop.—The facilities for repair welding are prescribed by *U. S. Bureau of Air Commerce*. These requirements should be considered as minimum for adequate execution of aircraft welding. The following facilities are outlined for welded repairs of steel structural tubing, and steel fittings:[1]

1. Stock room with provision for segregation of materials.
2. Record system for all work.
3. Drafting equipment for preparation of drawings.
4. Room facilities with proper heat, ventilation, lighting, and safe handling of gases under high pressure.
5. Licensed personnel which is qualified to perform or supervise welding.

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[1] See also Par. 11 for additional welding equipment.

6. Oxyacetylene-welding equipment with the proper range of torch tips and supplies.
7. Portable buffer.
8. Bench and vise.
9. Power emery wheel.
10. Hand tools such as hack saws, clamps, tools for laying out fittings, micrometers for tubing and flat sheet, level, and a full set of reamers.
11. Cutting and forming tools.
12. Portable drill and drill press with full assortment of drills.
13. Magnifying glass with 10 to 20 minimum power.
14. Long and short trammel rods with adjustable points for alignment of fuselage bays.
15. Adequate supply of all standard sizes of S. A. E. 1020 and S. A. E. 4130 tubing and sheet (in stock or readily available).
16. Supplies and equipment for painting and applying protective coatings to outside and inside of tubing and fittings.
17. Supply of necessary small standard parts.
18. Soldering equipment and supplies.

80. Classes of Aircraft Welds.—The welds, most generally used in aircraft are the gas-flame weld, the metallic-arc weld, and the resistance weld.

By the *gas weld* is meant the fusion weld in which the welding heat is produced by combustion of a mixture of acetylene and oxygen or of hydrogen and oxygen.

The *metallic-arc weld* is a fusion weld in which the welding heat is supplied by an electric-arc flame between the parent metal (tubings, fittings, etc.) and the electrode. The electrode, which is an electrical conductor, is the welding wire which, when melted in the arc flame, supplies the metal for the gap between the interfaces of the adjacent parts at the weld.

The principle involved in *resistance welding* may be described in the following manner: The resistance offered by a poor electrical conductor, such as steel, when clamped by electrodes of high conductivity, such as copper or copper-tungsten alloys, develops a more rapid heating in the steel conductor than in copper. By superimposing a pressure on the electrodes of sufficient concentration, when the grain growth and recrystallization have developed with electrical heating, the mating surfaces become locally interlocked but not necessarily fused. When metals, such as aluminum, which have high electrical conductivity, are resistance-welded, satisfactory welds are obtained by reducing the time of current passage and by *dumping* currents of higher magnitude than required for steel.

81. Equipment for Gas Welding.—For gas welding, the following apparatus is required:

1. *Oxygen and hydrogen tanks* to withstand 3,000 lb. per square inch pressure at 70°F. and store 100 to 220 cu. ft. These tanks are protected by safety diaphragms which burst at 3,000 lb. per square inch when excessive heat surrounds the tanks (see Fig. 64).

2. *Acetylene tanks or an acetylene generator* for acetylene supply. Acetylene from tanks is dissolved in acetone and retained in the absorbent asbestos and clay tank lining (Fig. 64). The acetylene available in these is referred to as dissolved acetylene.

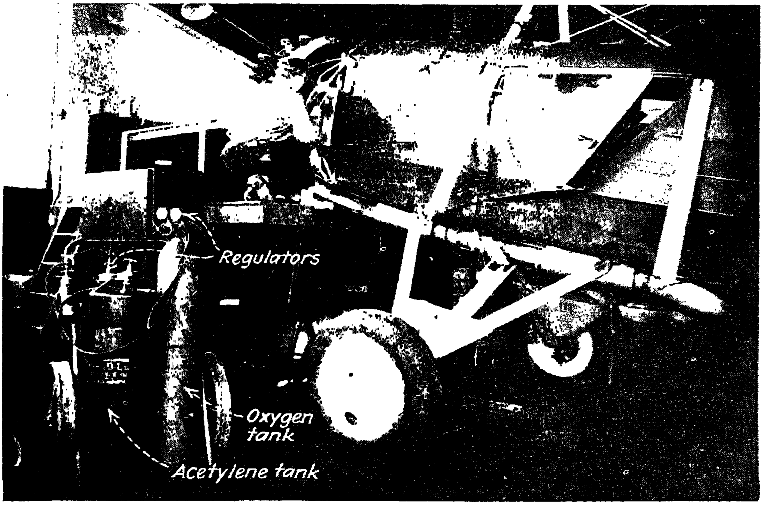


Fig. 64.—Oxygen and acetylene tanks, regulators, and equipment, portable unit. (*Courtesy of The Linde Air Products.*)

The generated acetylene requires a suitable generator similar to that described in Par. 84.

3. *Regulators* to reduce the tank pressures and control the flow of gas to the torch. There are two types of oxygen regulator, the single-stage and the two-stage. The two-stage type (Fig. 65) is preferred since it provides a steady, uniform flow of oxygen which provides a constant torch flame. Acetylene regulators are of the single-stage type.

4. *Manifolds and hose* to provide for the safe distribution of gases from the tanks or gas supply to the torch.

5. *Welding torches or blowpipes* to mix the acetylene or hydrogen, when designed for separate use of each gas, with oxygen. Each torch is equipped with a mixing nozzle which has the function of proportioning each gas for

the maximum flame temperature. The character of the flame varies in a manner shown in Figs. 72 and 73.

6. *Goggles* for protecting the eyes from eye strain and hot metal. Goggles are provided with colored lens, either amber- or green-tinted, to soften the reflected light of the molten steel and permit a detailed study of the molten weld. Either the strap goggles or helmet goggles are available. *Under no circumstances should these goggles be used to witness electric-arc welding,* since temporary blindness may be caused.

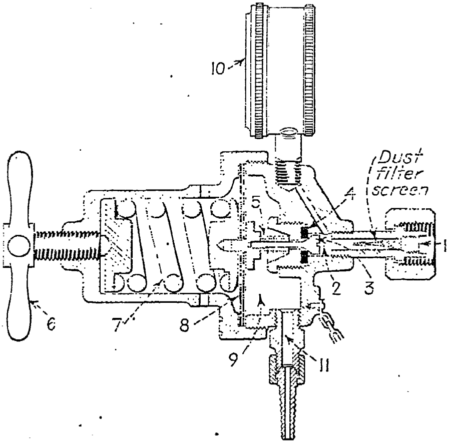


FIG. 65.—Single-stage stem-type regulator; safety diaphragm not shown. (*Courtesy of Linde Air Products Company.*)

7. *Welding wire,* often termed filler rod, for supplying metal in the gap between the interfaces of metal.

8. *Accessories* such as *spark lighters* and *gloves.* Each piece of this equipment provides the means of preventing serious burns, the spark lighter when lighting torches and the gloves during welding operations.

82. Gases for Aircraft Welding.—*Oxygen,* which is one of the principal and abundant chemical elements, is necessary to support the combustion of acetylene or hydrogen. While oxygen itself does not burn, it causes other substances to burn. *Oily gloves or waste, and paint will burn violently in the presence of commercial oxygen.* Thus it is apparent that oxygen leaks should be prevented. Oxygen leaks, however, are difficult to detect since oxygen has neither odor, taste, nor color.

Small leaks are found in hose and manifolds by soap suds made from only pure castile or ivory soap, or glycerin. The suds froth or bubble at the source of leaks. At high pressures, such as encountered in welding, loss of oxygen is accompanied by a hissing sound at the leak. Oxygen at a high pressure *expands* rapidly in volume from the tank pressure to atmosphere pressure, propelling objects in the immediate vicinity with considerable velocity. These objects have been known to be parts of the tanks themselves, and *parts of human bodies.*

83. Safety Precautions for Oxygen.

1. Keep oily or greasy waste, hose, hands, gloves out of contact with oxygen.
2. Keep oxygen fittings tight to prevent loss of oxygen and possible explosion.
3. When regulator-threaded fittings do not screw on easily, the wrong regulator is being used or an adapter fitting is required.
4. Never connect an oxygen regulator to a tank containing acetylene. compressed air (which usually contains oil) or any combustible gas, or *vice versa. Explosions will result.*

84. Acetylene Gas.—This is a colorless gas containing 2 parts, by weight, of carbon and 2 parts by weight of hydrogen (C_2H_2). It has a pungent odor, often nauseating in its effect. Acetylene is generated from calcium carbide in contact with water.

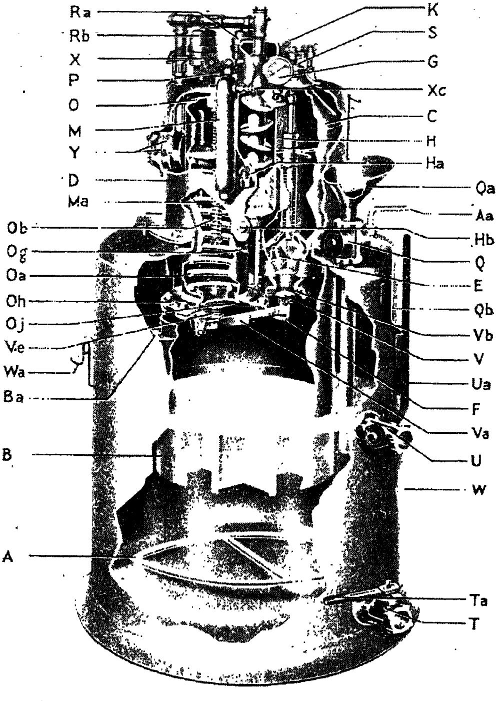
Calcium carbide is nonexplosive. When not in use carbide is stored in airtight drums to prevent the formation of acetylene.

Acetylene, which is generated from calcium carbide, is inflammable and explosive in air between the following limits: 2 per cent acetylene by volume with 98 per cent oxygen by volume, and one half air and one half acetylene by volume. At pressures in excess of 30 lb. per square inch, *acetylene is apt to explode,* or burn combustible materials. Low and medium pressure acetylene generators maintain operating pressures below this limit and are sealed to prevent mixing of air and generated acetylene.

85. Generated Acetylene.—Acetylene is formed in suitable generators, for example, as shown in Fig. 66. The type illustrated is of the carbide-to-water type. In this type the carbide is distributed by a revolving plate so that the calcium carbide particles fall into a large bath of water, thus generating the gas with a minimum of heating from the chemical reaction. *This type of generator is for stationary practice such as is required in the repair shop or manufacturing plant.* All parts are accurately fitted. The feed mechanism is covered to be dust-tight and yet to be readily accessible for adjustments and replacements.

The *feed mechanism* is a cylinder with a circular opening at the bottom and a revolving circular plate suspended on the vertical motor drive shaft, which extends through the hopper to the driving mechanism. The carbide falls on this revolving disk and is swept off by scrapers projecting from the hopper.

INSTRUCTIONS FOR OXWELD TYPE MP-7 ACETYLENE GENERATOR



KEY TO FIG. 66.

- *A*. Residue agitator
  - *Aa*. Handle
- *B*. Splash baffle
  - *Ba*. Support baffle
- *C*. Carbide hopper
- *D*. Dome
- *E*. Carbide feed valve cleaner
- *F*. Feed lock rod
- *G*. Pressure gauge
- *H*. Hydraulic back-pressure valve
  - *Ha*. Water-level plug
  - *Hb*. Drain plug
- *K*. Interference lever
- *M*. Moisture trap
  - *Ma*. Drain plug
- *O*. Feed-control housing
  - *Oa*. Spring
  - *Ob*. Pressure-adjusting screw
  - *Og*. Vent pipe
  - *Oh*. Flange
  - *Oj*. Diaphragm
- *P*. Pressure-adjusting handwheel
- *Q*. Water-filling valve
  - *Qa*. Funnel
  - *Qb*. Handle
  - *Ra*. Generating chamber relief valve
  - *Rb*. Hydraulic back-pressure valve relief valve
- *S*. Carbide charging door
- *T*. Residue valve
  - *Ta*. Handle
- *U*. Water-overflow valve
  - *Ua*. Handle
- *V*. Carbide feed valve
  - *Va*. Feed-valve lever
  - *Vb*. Rubber seat
  - *Ve*. Feed-lever spring
- *W*. Water shell
  - *Wa*. Handle
- *X*. Service valve
  - *Xc*. Hose connection
- *Y*. Filter pads

FIG. 66.—Schematic drawing of medium-pressure generator. Oxweld Type MP-7 Acetylene Generator. (*Courtesy of Linde Air Products Company.*)

A diaphragm regulates the rate of acetylene generation by actuating a simple lever attached to the feed mechanism. This driving mechanism is propelled by a weight which descends at a rate determined by the speed of the flyball governor. Thus the carbide is fed only as fast as required. The generator is equipped with pressure-relief valves so that the pressure is maintained at less than 20 lb. per square inch.

Provision is made to remove mineral and chemical impurities from the generated acetylene. Fine lime dust is the most important impurity removed. Hydrogen sulphide (H_2S) and water vapor are eliminated from the acetylene in the best type of generator. The presence of lime dust and hydrogen sulphide in acetylene impairs the strength of a gas weld because these impurities are carried by the flame into the molten weld where the lime dust forms large voids or brittle inclusions, and sulphur in H_2S embrittles the weld.

86. Dissolved Acetylene.—After acetylene has been generated, it is possible to store it safely for later use in acetone at pressures in excess of 235 lb. per square inch. This is termed dissolved acetylene in contrast to generated acetylene. The dissolved acetylene is more expensive than generated acetylene, but in tanks as shown in Fig. 64 it is convenient for portable use in the repair station.

Dissolved acetylene is distributed in steel cylinders similar to Fig. 64. Eighty per cent of the capacity of the acetylene tank is occupied by porous absorbent material which is saturated with *acetone.* The porous, absorbent tank lining serves important purposes: *First,* to divide the acetylene in fine particles and eliminate the possibilities of explosion; *second,* to provide space for the acetone which expands upon dissolving acetylene. Acetone dissolves 24 *times* its own volume of acetylene at 60°F. for every atmosphere (14.7 lb. per square inch) of pressure. For instance, at 225 lb. per sq. inch in an acetylene tank (Fig. 64) the acetone dissolves 368 times its own volume in acetylene with a volume increase of 60 per cent for the acetone.

87. Safety Precautions for Acetylene.

1. *Fuse plugs on acetylene tanks are to be left intact and not unscrewed.* These plugs protect the tank from explosion when excessive heat is present near the tank since the top surface of each plug is covered with a low-melting-point metal, which when melted, uncovers an opening through which acetylene escapes.

2. *Avoid open contact of acetylene and oxygen.* In combination without proper mixture (which is rarely possible except in correctly designed torches) these gases are violently explosive and destructive. To prevent this possibility of open contact, *acetylene hoses are made red with left-hand fittings,* while *oxygen hoses are made green with right-hand fittings,* so that hoses cannot be interchanged.

3. *The safe maximum pressure on the low-pressure side of the acetylene regulator is* 15 *lb. per square inch.* Above 15 lb. per square inch any sudden

fluctuation often precipitates acetone into the regulator where the valve seats, and passages are clogged so that the pressure builds up to *explosive* valves.

4. *Release diaphragm on the regulator* (Fig. 64) *when closing down apparatus* to prevent the feeding back of water from the hydraulic flashback chamber, Fig. 69, and clogging the regulator.

5. *Close tank valves when acetylene tanks are empty* to prevent evaporation and loss of acetone. Mark empty tanks with letters M.T.

88. Hydrogen.—Hydrogen is used with oxygen in torches to produce heat for aluminum welding. *Hydrogen is a colorless, tasteless, odorless, and inflammable gas. It explodes* in air at 612°F. and in commercial oxygen at room temperatures. Detection of leaks must be by glycerin or soap suds as for oxygen and under no circumstances with a lighted flame. Special regulators and torches must be used for the mixing of hydrogen and oxygen or compressed air. Since hydrogen displaces oxygen or air in the lungs, welding should be done in well-ventilated rooms.

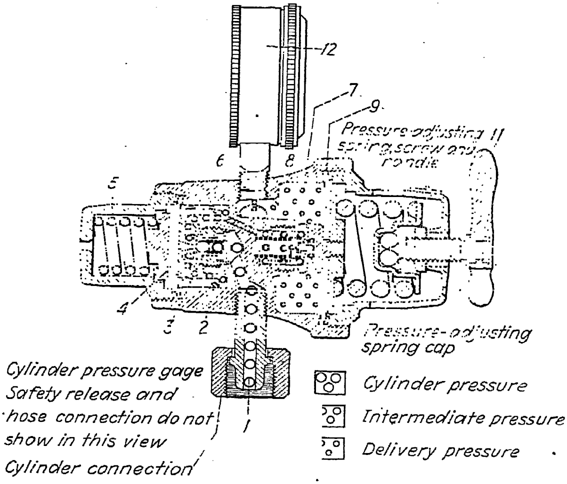

12
7
9
Pressure-adjusting 11 spring, screw and handle
6
8
5
4
3
2
1
Pressure-adjusting spring cap
Cylinder pressure gage Safety release and hose connection do not show in this view
Cylinder connection
Cylinder pressure
Intermediate pressure
Delivery pressure

FIG. 67.—Two-stage oxygen regulator for aircraft welding. (*Courtesy of Linde Air Products Company.*)

89. Safety Precautions for Hydrogen.

1. *Hydrogen must be kept from the vicinity of open flames.* Use only torches prescribed for burning hydrogen.

2. *Avoid contact of oxygen and hydrogen because an explosion will result.* Oxygen hoses should not be used for hydrogen.

3. *Store hydrogen tanks in cool, dry place at 70°F.*, but not at a freezing temperature, because traces of moisture freeze in the tank or regulator stopping the hydrogen flow to the torch.

4. *Repair leaks only after the hydrogen is shut off at the supply tank.*

90. Regulators.—A regulator serves two purposes: *First,* to reduce pressure from the tank or supply to the lower pressure at the torch; *second,* to control the flow of gas without variation as the tank pressure decreases. *The regulation and reduction of pressure is obtained by interposing one or two nozzles between the high-pressure and low-pressure sides.* When *one nozzle* is used, the regulator is known as a *single-stage regulator* (Fig. 68). The regulator which reduces the pressure in *two successive nozzles is called a two-stage regulator* (Fig. 67). These are representative of the two fundamental types of regulators.

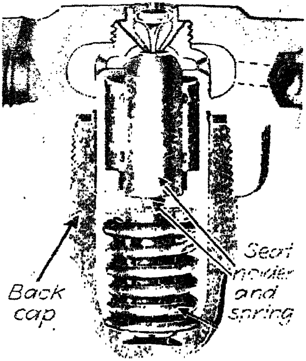


FIG. 68.—Nozzle-type regulator for aircraft welding. (*Courtesy of Victor Welding Equipment Company.*)

Where large volumes of oxygen flow during the cutting of steel (Par. 105) the stem type (Fig. 65) provides ample capacity. *Overloaded nozzle-type regulators (Fig. 68) tend to freeze when used for supplying oxygen in cutting or burning steel.* The rapid expansion at the nozzle and its seat (Fig. 68) lowers the temperature enough to chill and free traces of moisture in regulator parts which have not been protected by dust caps from the infiltration of moist air when disconnected.

In the *oxygen-metering mechanism* (Fig. 65) the oxygen passes from the high-pressure side 2 to the stem 3. The pressure at this point is registered on the high-pressure (not shown) gauge. The metering stem 3 extends from the high-pressure chamber 2 to the low-pressure space 9. The oxygen on the high-pressure side forces the stem against its seat 3 except when depressed by the crossbars 6. Control spring 6 assists the high-pressure oxygen in seating the stem 2, and damping out any fluctuation in oxygen flow during cutting.

By turning the crossbars 6 in a clockwise motion when facing the front of the regulator, spring 7 is compressed and depresses the diaphragm 8. By this means the pressure is increased to a working value which is registered on the low-pressure gauge 10. As the stem moves away from its seat 4, the oxygen passes through the cavity around the stem into low-pressure space 9, thence through the hose ferrule 11 into the hose.

For the operation of this type of regulator, with the tank, regulator, hose, and torch connected, take the conditions when the torch valves are closed and no oxygen is leaving space 9 when the low-pressure gauge is reading 15 lb. per square inch.

What preceeded this condition was that the valve stem 3 had been moved away from its seat 4 by turning the crossbars clockwise until the pressure in space 9 reached 15 lb. per square inch. Instead of the stem 3 remaining off of its seat, the following operations occur automatically. The oxygen as it flowed by the stem filled the low-pressure space 9 until 15 lb. per square inch was exceeded. Then the excess pressure deflected the diaphragm, and by means of spring 5 the valve stem moved with the diaphragm. The movement of stem 3 with the diaphragm 8 finally shut off the high-pressure side by forcing stem 3 against its seat 4. Should the pressure in space 9 be released for any reason, such as opening the oxygen valve on the torch, a portion of the compression of spring 7 is released, and the diaphragm 8 forces the stem 3 away from its seat until the opening is sufficiently large to supply oxygen at 15 lb. per square inch.

The *two-stage regulator* (Fig. 67) has the same operating principles which have been discussed for the stem-type regulator, except that the reduction from tank pressure to working pressure is obtained in two separate stages. In this type of regulator, precision control of the oxygen flow is possible with very slight, if any, fluctuation in the low-pressure oxygen supply.

91. Two-stage-regulator Operation.—Where a small flame, as in aircraft welding, requires fine adjustments and close regulation without pressure fluctuation, this type of regulator (Fig. 67) has found wide acceptance.

The oxygen enters at highest pressure through passage 1 and around stem 2 in the first pressure-reduction stage. The stem 2 is held from its seat by a spring and diaphragm 4 which is so adjusted by the manufacturer to deliver oxygen at 150 to 200 lb. per square inch to the second stage through part 6. There are two instances when the stem 2 is held from seating at 4: First, when the tank pressure is between 15 to 200 lb. per square inch; and second, when supply tank pressures are less than those set by the welder for the second or final pressure stage. In either instance the second stage is adjusted by the crossbar and automatically maintains the pressure since the valve stem 2 in the first stage is wide open permitting the second stage (7 to 12, inclusive) to function as a single-stage regulator (Fig. 65). The first-stage control requires no external adjustment, if left with factory settings for pressure and volume.

92. Nozzle-type Regulator.[1]—The mechanism for pressure control in this type of regulator differs fundamentally from the stem type in the pressure-reduction mechanism. A typical regulator of this type is shown in Fig. 68. The oxygen at high pressure passes through the filtering screen inlet, which appears with the dust cap in place when disconnected from the tank. The oxygen flow branches to the high-pressure gauge and to the stationary nozzle.

The nozzle seat is a part of the valve body. This sleeve is hollowed out on the top side to accommodate a spring and nozzle body (see Fig. 68). When a screw is turned counterclockwise, facing the front of the regulator, the diaphragm is relaxed and the spring expands to hold the nozzle seat against the stationary nozzle opening with sufficient pressure to prevent leakage past this seat surface.

By turning the adjusting screw clockwise, when facing the front of the regulator, the spring is compressed. The diaphragm presses against the end of the valve sleeve, compressing in turn a valve spring which opens a space between the nozzle and the seat. Oxygen then passes from the high-pressure side into the low-pressure space, with reduced pressure, and out into the hose.

Any fluctuation in the oxygen flow is reduced by the use of springs which act to cushion or dampen the oscillation. Consequently, the sensitivity and accuracy of this type of pressure regulator depends upon the wear resistance of the nozzles and their seats, and upon the durability of the springs, diaphragm and sleeve.

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[1] This regulator is often used with acetylene as the gas except that lower pressure gauges are used and the body of the regulator is painted red (denoting acetylene) instead of green (for oxygen).

93. Preparation for Using Regulators.—The tank valve is opened slightly for an instant and then closed. This is known as *cracking the valve;* it removes dirt or dust which otherwise would enter the regulator screen and clog the passages. *The operator should stand at the side of the valve instead of in front when performing the operation.* Connect the union nut of the regulator to the nipple on the tank valve. Release the crossbars or adjusting screw until the screw turns freely but not so far as to allow them to drop and break the crossbars or burr the threads. Fasten hose-coupling nuts on the regulator. Then open the oxygen-cylinder valve. Turn adjusting screw or crossbars clockwise or to the right until the oxygen passes through the hose to clear it of any dirt or "talc" (when the hose is new) which would be carried into and clog the mixer of the torch. Unscrew the adjusting screw to shut off the low-pressure oxygen. Connect the torch to the hose when valves are closed and turn on the oxygen until the desired pressure is obtained.

Acetylene.—Before connecting acetylene regulators, *check the cylinder valve for leaks by either smell or soapy water, never with flame or match, if you value your life.* Do not use leaky tanks, but notify the supplying company and follow their instructions as to its return. Crack the valve on good tanks. Attach acetylene regulator, noting that the threads are left-handed. Check union at the regulator-tank connection for leaks and tighten if you are certain that the regulator is the correct one or the correct adapter is used.

Use the same procedure in attaching the hose and torch connection as outlined for the oxygen equipment. Check the gauges frequently for pressure increase or *creeping* due to faulty or worn seats or dust. If *creeping* occurs, have the regulators repaired or cleaned by experienced, reliable regulator-service men.

94. Back-pressure Valves.—Distribution of acetylene in large quantities requires a generator supply, because the manfolding of dissolved acetylene tanks is more expensive and involves more handling than generated acetylene. For repair stations using generated acetylene at low pressure the back pressure resulting from flashbacks causes the reversal of acetylene flow. *To prevent the backfire from reaching the generator or acetylene supply tanks, back-pressure valves are used.* A typical back-pressure valve (Fig. 69) requires little attention, except checking of the water level periodically, and continues to function instantly when the correct installation has been made by experienced equipment manufactures.

In operation, the hydraulic type of back-pressure valve (Fig. 69) allows the acetylene from the supply to enter through the delivery tube and to proceed in the direction of the arrow. The acetylene in its flow is bubbled through the water into the chamber communicating with the acetylene-hose connection. Should the acetylene be compelled to flow in the reverse direction, owing to a pressure of 10 oz. or more per square inch built up during a back pressure or possibly excessive oxygen pressure in the balanced-pressure type of welding torch, the level in the water seal is depressed, since the water cushions the reverse flow by changing level. If the reversed flow is persistent and of the proper magnitude, the water seal *B* is broken and the mixture rises through the vent tube into the atmosphere through the vent pipe. When the *back-pressure* (which this reversed pressure is called) ceases, the water returns to its normal level, sealing *B* with water.

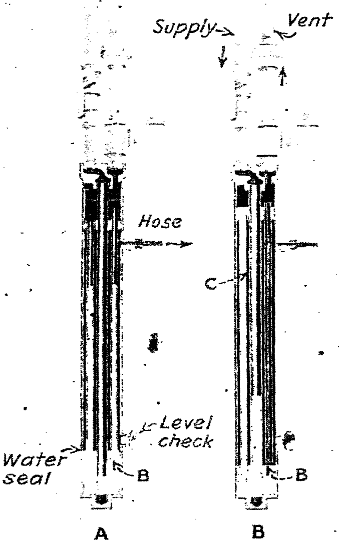


FIG. 69.—Hydraulic back-pressure valve. (*Courtesy of The Linde Air Products Company.*)

A less effective means of preventing damage from backfires will be found on acetylene manifolds in hollow coupling sleeves, filled with finely divided lead shot. These sleeves are connected in the line from the manifold to the dissolved acetylene tank.

95. Manifolds.—When single cylinders furnish insufficient acetylene or oxygen, several cylinders are connected in rows by *pigtail* tubes to a horizontal supply line. The pigtail connection allows for the expansion and contraction and makes the connections adaptable to cylinders which usually vary slightly in height.

The usual manifold connections are made so that 4, 8, 10, 20, or 30 cylinders are tied onto the manifold. Only half the total number, that is, 2, 4, 5, 10, and 15 supply oxygen or acetylene at one time. When one side of the manifold is exhausted, it is turned off and the remaining tanks are opened. In this manner the empty tanks are replaced by full tanks without interferring with the supply for welding. *Manifold construction and installation must conform to municipal, state, and national laws and therefore should be installed by manufacturers of this equipment or their agents.*

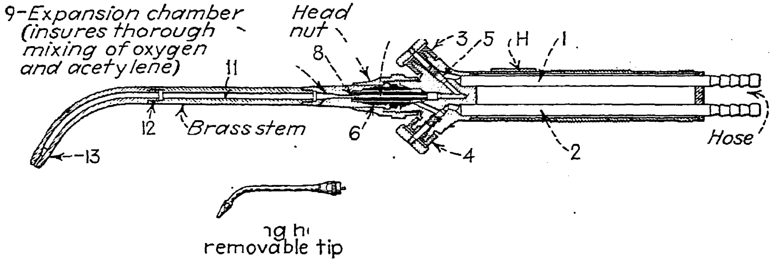
96. Accessory Welding Equipment.—All regulators are fitted with pressure gauges. For *oxygen,* the high-pressure gauges read to 3,000 lb. per square inch at sea level and for graduations in pressure below 2,200 lb. per square inch are marked for oxygen in cubic feet. The low-pressure gauges on each oxygen regulator registers to 50 or 100 lb. per square inch for welding, and for cutting pressures to 400 lb. per square inch. *When bringing up the pressure on the regulator, it is safe to stand at the side of gauges since a gauge is much stronger at the side than in front or back.* The back of the modern regulator is snapped on so that with the failure of the gauge, the back blows out.

Acetylene gauges are of two kinds, the high-pressure gauge registering 350 lb. per square inch maximum, and the low-pressure gauge reading to 15 lb. per square inch. No graduations appear above 15 lb. per square inch because this pressure is considered the safe maximum pressure for acetylene lines.

97. Welding Torches or Blowpipes.—Two purposes are served by welding torches: *First,* to mix oxygen and acetylene or combustible gas in the most efficient combination and in safe proportions for these gases; and *second,* to direct and concentrate the heat resulting from gas combustion at the weld. Valves are provided on the torch to control the mixture of acetylene or hydrogen and the oxygen. *Only by the manipulation of the torch valves is it possible to control conveniently the size and nature of the flame.*

Welding torches for aircraft use are of two general kinds: *The injector type,* operating at pressures in excess of 1 lb. per square inch for acetylene, and average oxygen pressure of 20 lb. per square inch; and the *balanced-pressure type* of torch in which the oxygen and acetylene are mixed at equal pressures.

The *injector type of torch* is illustrated in Fig. 70, and operates as follows: The grip handle *H* shields oxygen tube 1 and acetylene tube 2 to the respective valves 3 seating at 5, and 4 seating at 6. With valve 3 off its seat, the oxygen flows into the center of mixer 7 until the passage is reduced in diameter at 8 where the oxygen gains velocity and the pressure drops sufficiently to suck the acetylene (when valve 4 is off its seat) into the oxygen stream leaving the mixing chamber at 9. Since the direction of flow is toward the lower pressure, the mixed oxygen-acetylene proceeds through the gooseneck tube 12 and through tip 13 where the mixer is lighted. The better types of injector torches provide for the mixed gases to expand at 11 just beyond the mixing chamber at 9 in order to intermix the gases thoroughly. Construction of the passage at 13 again increases the velocity as the gases leave the tip. The amount of heat available at the tip is provided by interchangeable larger or smaller sizes depending upon the thickness of metal being welded. The tip sizes are listed in Table X for different thickness of metal. The recommendations of torch


9-Expansion chamber (insures thorough mixing of oxygen and acetylene)
Head nut
8
3
5
H
1
11
12
Brass stem
6
4
2
Hose
13
ng h
removable tip
FIG. 70.—Injector-principle welding blow pipe.

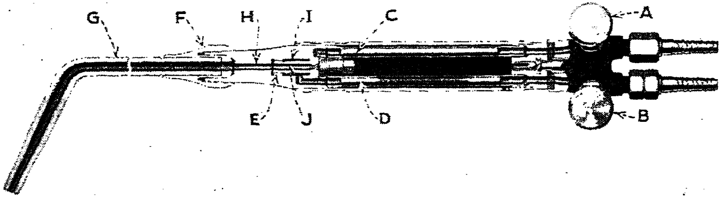


FIG. 71.—Balanced-pressure welding blow pipe. (*Courtesy of Linde Air Products Company.*)

manufacturers for tip sizes and different thicknesses of metal should be followed for effective welding.

The *balanced-pressure* type of torch is shown in Fig. 71. The oxygen and acetylene are regulated by the opening of valves *A* and *B*, whence they pass through their respective tubes *C* and *D* at equal pressure to the mixer assembly *E*. The mixed oxygen and acetylene are first expanded in tube *H* and contracted in *G*. The same operations are repeated where the gases escape to the atmosphere and are ignited off the goose-neck tip *G*. The alternate expansion and contraction serves to mix the gases thoroughly and supply a steady flow of gas mixture in correct proportions.

The most common difficulty in handling the torch during welding, is the flashback or backfire, which is attended by a telltale popping noise. This condition must be prevented in order not to burn and damage hose linings and regulator parts and not to coat the welding-tip passages with unburned carbon which aggrevates the difficulty. A list of typical causes of backfiring should serve to suggest the remedy of this difficulty as follows:

1. *Overheated tips* expand or enlarge the tip bore so that the oxygen-acetylene ratio is changed to a leaner mixture which tends to backfire as does a lean mixture in an automobile carburetor. *Remedy is found in holding the tip farther from the molten welds.*
2. *Unsteady flow of oxygen* when dirt has lodged in torch passages. Clean oxygen and acetylene-tank outlets and regulator connections to prevent clogging of regulator and torch passages.
3. *Building up of pressure* at dirty or clogged tips after gases have been mixed. Remedy is to clean tip with drill of proper size (see Table X). Use of rough-ended wires scores the tip bore and leads to faulty gas delivery.
4. *Stoppage of oxygen or acetylene flow* through hoses when the hoses are kinked or heavy objects are resting upon it. Long hoses over 25 ft. should be avoided as a means of reducing kinks.
5. *Leakage of oxygen or acetylene* or both at their valve seats. Reseating of valves should be done with special tools by competent service mechanics.
6. Most serious backfires occur when *connections are loose so that acetylene is escaping.* Be certain that all hoses are tight before lighting the torch.

The usual difficulties encountered in torch and regulator operations and how to recognize and remedy them are fully described in the instructions issued by the educational committee of the American Welding Society. All apprentice welders should possess a copy of these instructions.

98. Welding Hose.—Hose for higher gas pressure than usually encountered are made of vulcanized fabric with rubber lining and rubber covering either corrugated or smooth, making a solid hose which is capable of withstanding a minimum pressure of 250 lb. per square inch. Smooth hose of small size is usually termed *leader hose.*

Oxygen hoses are green when new and are fitted with right-handed threaded fittings. The word oxygen is vulcanized on the exterior of the hose at intervals.

The acetylene hoses are red and are fitted with left-handed connectors which prevent the possibility of interchange with oxygen or compressed-air hose. The word acetylene is vulcanized at intervals on its exterior throughout its length.

New hose is often lined with a sprinkling of fine talc to preserve the rubber lining and absorb moisture. *The talc must be blown out with oxygen if it is an oxygen hose or with acetylene if it is an acetylene hose,* being careful to use acetylene sparingly since it is combustible when blown through the hose near open flames above a temperature of 1400°F. in air.

Hoses should be coiled and not kinked, and heavy objects should *not* be allowed to rest upon them, otherwise flaskbacks are apt to develop and injure and weaken the hose fabric. Lengths of hose over 25 ft. should be avoided, since it is difficult to prevent kinks in long lengths of hose.

99. Welding Rods.—The metal deposited between adjoining plates or tubes is obtained from filler rods. *Welds of high quality are reliable only when the rod metal is free from impurities.* Inferior rods of low-grade quality are available for less than the best welding rods. The best quality of rod is essential to the reliability of welded joints.

A welding rod of good quality under the flame melts evenly, easily, and quietly without sparking, and coalesces into a deposit free of surface cracks, and smooth in texture. These indications are superficial and unless chemical analyses are made of the rods, one must rely on the experience of reliable and established manufacturers of welding rods.

Many welding rods are surfaced with a coating of grease or copper. These compositions do not interfere with the weld metal so much as the rust or oxide which would be present if it were not for the surface treatment.

For steel welding, cold-drawn steel rods are used. For brazing of fittings and parts, bronze or brass rods are used for filler metal. However, a brazed fitting cannot be welded with a steel rod. But a steel-welded part may be brazed.

Aluminum and its alloys, especially duralumin, are welded with drawn-aluminum rods the better type containing 5 *per cent silicon*

TABLE X.—SUMMARY OF SPECIFICATIONS FOR WELDING MATERIALS

Base material, sheet	Welding rod	Welding rod specification	Flux
Low carbon......	Low carbon	AC 10286	None
Steels and X-4130	Copper-coated metallic-arc electrode	GR-1-G AC 10286-GR 1E or 5E	None Navy 51F3
AISI 347........	Stainless Columbium Stabilized	AC 10286 GR 3-G Navy 46R2	Cromaloy or AC 11314
Inconel or Inconel to stainless.	No. 42 Inconel	Army 57-174 USAC 10286 Navy 46R6-GR 3E	Inconel Flux Cromaloy or AC 11315
2S, 3S, 43S, 51S, and 53S.	Aluminum or aluminum-silicon (5%) (2S or 43S rod)	Fed. QQ-R-571 Type D or E	AC 11313 or Alcoa 22
52S	Aluminum 5% Silicon or 52S	Fed. QQ-R-571 Type E Ord or Navy 46A11	AC 11313 or Alcoa 22
AM3S...........	AM3S rod	Navy M-314 AC 11322	Navy F-15 AMC 13 or Alcoa 22 AC 11323
AM265	AM53S rod	Navy M-314 AC 11322	Navy F-15 AMC 3 or Alcoa 22 AC 11323
AM3S to AM53S	AM53S rod	Navy M-314 AC 11322	Navy F-15 AMC 3 or Alcoa 22 AC 11323
Stellite..........	Stellite No. 1 or No. 6	AC 10300	None except excess acetylene flame

and a proper flux. Cast aluminum is welded with cast-aluminum rods.

Copper is weldable only with deoxidized drawn-copper rod with a flux of 90 per cent borax and 10 per cent sodium fluoride.

100. Welding Fluxes.—A flux is any chemical compound which combines with oxygen or with metallic oxides (compounds of metal and oxygen). The presence of oxides in a weld forms *voids* or "cold shuts" which reduce the weld strength. A *flux* functions in three ways:

1. To form a chemical compound of oxygen and the oxides which is known as slag. The slag which is fusible is always the most desirable.

2. The resulting slag is lighter in density than the metal being welded and will rise to the top of molten metal of the weld if not disturbed, or it may be incorporated in the weld by puddling or stirring with the welding rod. When the slag has floated to the surface, it acts as a protective film which prevents the entrance of more oxygen into the weld. For this reason good fluxes do not vaporize or escape easily from the weld into the air.

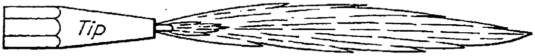
The flux used in aluminum and duralumin welding is corrosive if left on the weld and must be washed off with a solution of warm water and 2 per cent nitric or hydrochloric acid, followed by a second rinsing with warm water. This procedure is known as the neutralizing treatment.

3. The better fluxes form a slag which melts at a lower temperature than does the weld metal so that the slag remains liquid after the weld has solidified. The slag is, as a result, squeezed out when the metal is solidifying if the slag is not buried too deeply in the weld by puddling.

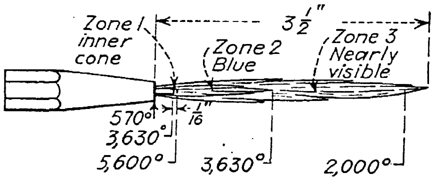
A flux is necessary when welding bronze, brass, copper, aluminum, duralumin, stainless steel, or when soldering lead-base alloys because the oxides of these metals are not molten at welding or soldering heats. The steels for airplane construction such as S. A. E. 1025 and S. A. E. 4130 form oxides which are always present to a limited extent with the best welding technique. But these oxides are molten at or near welding heats and float to the surface without the use of flux.

So-called flux-coated rods for steel welding possess fluxing elements which combine to form a slag that acts as a protecting film and prevents contamination of the weld with air. Where *washed coatings* are used on arc-welding electrodes, the effect is to *stabilize* the electric arc with little or no fluxing action on the deposited metal.

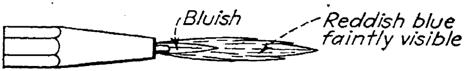
101. Welding Flames, Oxyacetylene.—The acetylene issuing from the torch tip is lighted so that the flame is out of contact approximately 1/16 in. from the end of the tip; with this flame setting, no further adjustment of the acetylene-torch valve will be necessary. All adjustment of the flame can then be made with the oxygen-torch valve which is opened after the acetylene is lit. *Goggles should be in place before turning on the oxygen.* The pure acetylene flame (Fig. 72*A*) is yellow, bushy in its spread, lazy, and sooty or smoky. It will be evident, in Par. 102, that this soot is pure carbon which is deposited in the molten weld metal if a flame of this kind is used. When oxygen is added to this flame, the yellow flame disappears and whitens until this coloring just disappears into a clearly defined incandescent, white inner cone, known as *zone* 1 (Fig. 72*B*). When the torch valve for oxygen reaches this adjustment so as to cause a recession from a fuzzy flame at *zone* 1 to a sharply defined cone of intense white color, the flame is known as *neutral.* It is neutral because the products of combustion (carbon dioxide and water vapor) (*zones* 2 *and* 3, Fig. 72*B*) have a neutral chemical effect on the metal being welded.



A Excess Acetylene, Reducing



B Neutral



C Excess Oxygen from Tank, Oxidizing

FIG. 72.—Oxyacetylene flames.

The *neutral flame* is the most satisfactory of all three oxyacetylene flames for airplane structural welding. Therefore, the aircraft welder must gain practice in obtaining and checking it as the welding proceeds. With the setting of the acetylene-torch valve as indicated on page 123, the flame adjustment can be controlled through the oxygen-torch valve alone. After securing the neutral flame, further opening of the oxygen-torch valve slightly produces an excess of oxygen in the flame. This flame is known as an *oxidizing flame* (Fig. 72*C*) and must be avoided. It is not used in airplane welding because the oxidizing flame leaves a weld weakened with iron oxide or other oxide inclusions which are oftentimes porous.

102. Nature of a Neutral Flame.—The neutral flame when produced by correctly designed torches has three parts: The *first* or *primary flame*, the *second-zone flame*, and the *third-zone flame*. (Fig. 72*B*.) In the first zone the acetylene is dissociated at about 1436°F. into carbon and hydrogen which unite with the oxygen from the cylinder to form carbon monoxide and hydrogen as expressed in the chemical Eq. (1).

$$C_2H_2 + O_2 = 2CO + H_2 \qquad (1)$$

All of the heat is not obtained until carbon monoxide (CO) and hydrogen have more oxygen available to combine with CO to form CO_2 (carbon dioxide) and with H_2 to form water vapor (H_2O). Zone 1 is *reducing* in its action because it takes oxygen from the atmosphere or from oxides to complete the combustion. Hence no oxidation or formation of oxides can take place in this zone. Welding in this zone is not advisable, since its temperature is low (Fig. 72*B*), and consequently, the welding speed is reduced. The flame is not stable in this zone 1 and is apt to carbonize and embrittle welds made in zone 1. *The best location of the plate or tube to be welded is with the surface of the molten puddle slightly less than* $\frac{1}{16}$ *in. off the tip of zone* 1, *where the temperature is a maximum* (Fig. 72*B*). Heat liberated from CO burning to CO_2 and H_2 to H_2O reaches its maximum value here. The temperature from this point outward becomes less because the oxygen, required for complete burning of CO and H_2, is taken from the air which is composed of 79 per cent nitrogen and 21 per cent oxygen by weight. The nitrogen is inert and is heated to the temperature of the flame at the expense of heat already in the flame, thus lowering its temperature. Air is always available for combustion of CO and H_2, since the heat generated by the burning of acetylene and hydrogen in zone 1 causes the warm gases to be displaced by cool air which in turn is heated and utilized as expressed in Eqs. (2) and (3).

$$2CO + O_2 \text{ (from air)} = 2CO_2 + N_2 \qquad (2)$$
$$H_2 + \tfrac{1}{2}O_2 \text{ (from air)} = H_2O + N_2 \qquad (3)$$

Hydrogen combines with air and begins to burn at 612°*F*. Hence, from Fig. 72, it is seen that the flame temperatures existing in zone 3 are better than three times that required for combustion of hydrogen. The result is that a surplus of air is present in zone 3 which mildly oxidizes or nitrides the metal welded or heated in this zone. Since *oxides* and *nitrides* (metal and nitrogen) impair strength, it is not advisable to weld or to anneal welds, plates, and tubing with this zone of the flame. It is not only slower but detrimental to weld and plate strength. Do all heating, annealing, and welding with surface of material being treated slightly less than 1/16 in. from the tip of zone 1 for best speed and satisfactory results.

103. Oxyhydrogen Flame.—In welding aluminum, a lower flame temperature is desirable since aluminum melts at 1182° to 1217°F., depending upon its purity. These temperatures are about half the melting points of steels commonly used in airplane welding. *Heating of aluminum causes shrinkage upon cooling which is twice that of steel, and, if this shrinkage is not provided for, the aluminum cracks.* Excessive heating of aluminum above its melting point produces serious contractions and shrinkages amounting to more than twice the shrinkage of steel. The minimum heat used in the welding of aluminum yields the best results. Therefore, preference is given to the use of the oxyhydrogen flame for this work.

104. Nature of Oxyhydrogen Flame.—For mixing of hydrogen and oxygen *only* the torches are to be used which are designed for these gases. *Torches for other gases are not to be used.* There are three characteristic oxyhydrogen flames. The *excess-hydrogen* (Fig. 73*a*), *neutral flame* (balanced proportions of hydrogen and oxygen, Fig. 73*b*), and *excess-oxygen* or *oxidizing flame* (Fig. 73*c*) are detected by the characteristic colors and the size of the flames.

When lighting the oxyhydrogen torch, turn on the hydrogen at pressures varying according to Table XII, and ignite hydrogen with a friction lighter. The resulting flame is a bluish, brownish yellow and lazy in its flow and should just leave the end of the tip about 1/32 in. Next turn on the oxygen-torch valve with a pressure for thickness of material being welded as shown in

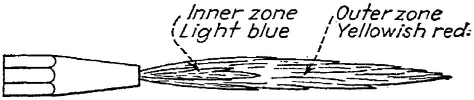
Table XII. As more oxygen is supplied to the flame, the flame becomes steady with little change in the amount or size of the zone 1, except that it is more clearly defined. The reaction here is expressed by the following equation:

$$2H_2 + O_2 + (\text{hydrogen in excess}) = 2H_2O + (\text{hydrogen in excess})$$

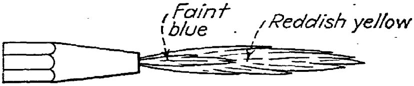
In zone 2 the oxygen of the air filters in to burn excess hydrogen as follows:

$$2H_2 + O_2(\text{from air}) = 2H_2O + N_2 \qquad (4)$$

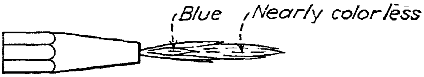
While this excess hydrogen is in zone 1 until burned in zone 2, it acts as a reducing agent to absorb oxygen from the air and weld and thus protects the weld from oxidation when the welding is done in zone 1.



(a) Reducing flame



(b) Neutral flame



(c) Oxidizing flame

FIG. 73.—Kinds of oxyhydrogen flames.

105. Shaping of Steel by Burning.—Parts of jigs and frames for holding aircraft parts are shaped from standard thicknesses of steel with the oxyacetylene or oxyhydrogen cutting torches. These flames serve only to preheat the steel preparatory to playing a jet of oxygen against the heated surface. The theory of burning or cutting steel is based on the fact that oxygen has a chemical affinity for steel above 1400°F. or a dull-red heat according to the following equation:

$$3\text{Fe(iron in steel)} + 2O_2 = \underbrace{\overbrace{Fe_3O_4}^{\text{slag}} + \text{liberation of heat}}_{\text{products of burning}}$$

The preheating flame heats the metal to a kindling temperature at nearly half the melting temperature of steel; and oxygen impinging against the heated surface burns the steel. Theoretically, burning is continuous after being started. But the loss of heat in surface accumulations of paint, rust, dirt, and grease lowers the kindling temperature of the steel and causes the burning to cease. Hence the requirement that a preparation of the surface by sandblasting, wire brush, scraper, or file is necessary.

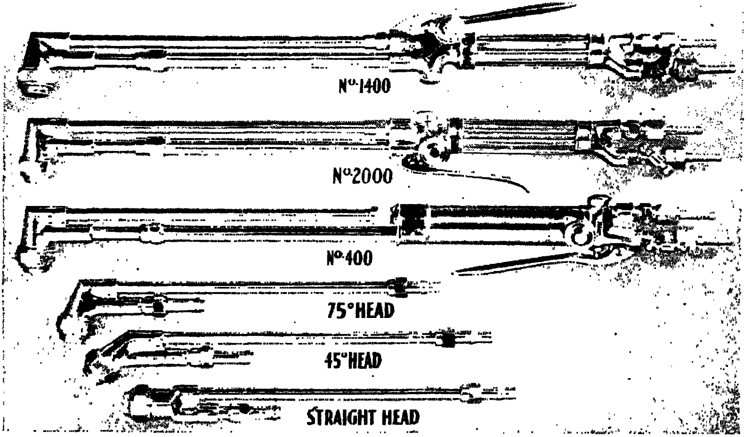


Fig. 74.—Cutting torches. (*Courtesy of Victor Welding Equipment Company.*)

The *cutting torch* combines the mixer for supplying the oxygen and acetylene for the preheating flames and independently the means of projecting an oxygen jet into the zone of heated steel. A typical cutting torch appears in Fig. 74, and the various torch tips are shown in Fig. 75. In these tips the flame in the drag tip or flames in the remaining tips of Fig. 75 burn in the outlying holes. *The center hole carries the oxygen for burning.* The heat generated by oxidation keeps the slag (Fe_3O_4, principally) molten, and under oxygen pressure it is driven clear of the cut or kerf and the underside of the plate. Slag, if it does adhere to the underside of the cut, may be embrittled by using a hard preheating flame (slightly reducing). Thus with chisel blows this slag is easily removed.

Metal cut by burning is equally as tough, strong, hard, and ductile, and the process is more rapid than methods of machine-tool cutting with metal saw, milling cutter, and abrasive wheel. Cutting speeds in excess of 1 ft. per minute have been obtained in steel less than 3 in. in thickness.

106. Electric Welding.—The heat of the *electric arc* is used in *fusion welding* of aircraft parts. Another kind of electric welding increasing in favor in production plants for miscellaneous parts is *resistance welding.* This method uses a large magnitude of current at low voltage which is *dumped* in adjoining metals, clamped with suitable electrodes under a compressive force. Sufficient heat is developed with a short-power impulse for each weld to forge-weld a limited area at the interfaces of the metals in contact.

107. Metallic-arc Welding.—The electric-arc welding used in airplane construction is a metallic-arc welding which is distinguished from other methods because it uses a metal electrode and metallic arc.

Both kinds of metallic arc have found acceptance in aircraft manufacture—the *direct current* and *alternating current.* The direct current is the flow of electrical energy in one direction from the high-voltage to the low-voltage side. Alternating current is characterized by the periodical reversal of the direction of electrical flow. The source of welding energy in the alternating-current method is a closed-core transformer with secondary taps for varying the welding current. This method has been used for only limited welding in airplane plants.

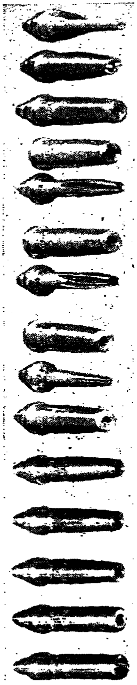


FIG. 75.—Cutting tips. (*Courtesy of Victor Welding Equipment Company.*)

108. Direct-current Welding.—The source of electricity is the direct-current generator with high-amperage capacity at low voltage (70 volts or less). The welding generator is driven by an alternating-current motor (Fig. 76). Another important part of the welding circuit is the choke coil or its equivalent (Fig. 76). Its purpose is to develop a counter- or opposing-voltage change for every variation in voltage at the arc and to stabilize the arc amperage, from which the arc heat is largely derived, at a constant welding current.

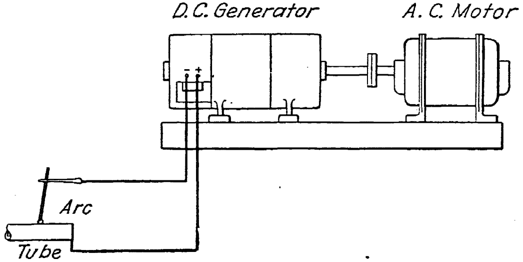


FIG. 76.—Metallic-arc welding circuit. Generator output, 40 to 350 amp. Arc stabilized by rotary pole adjustment. (*Courtesy of Roe Welders, Inc.*)

109. Characteristics of the Metallic Arc.—The greatest heat of the direct-current arc is concentrated at the positive side. Since the work has the greater volume of metal, the work is made positive (+) in polarity to insure sufficient temperature at the rod by the heat reflected from the arc crater. Reversal of this polarity (that is, the work is made negative and the electrode positive) is used with some coated electrodes and metals which oxidize readily.

110. Metallic-arc Theory.—With sufficient voltage (20 volts minimum) to break down the air gap, the arc gases are ionized and become electrical conductors. The passage of current in this atmosphere exhibits itself as heat in three distinct zones, namely, the arc core, stream, and flame. The heat which is liberated melts the parent and rod metals in the vicinity of the arc, forming plastic iron globules, which proceed from the electrode to the work. While projected toward the work, the globules gain heat, and as the molten-iron globules approach the crater, capillary forces consolidate them into the molten puddle (see Fig. 77).

The arc length in airplane welding is $\frac{1}{16}$ *in. for the usual electrode diameter* (Table XIII). Greater arc lengths than this permit contamination of the arc stream with oxygen and nitrogen from the air. This usually results in the hot-metal globules being ignited, followed by mild explosion as they intermingle. The hot metal is splattered by a long arc, leaving barnacles of hot metal near the weld deposit and a porous weld of doubtful strength. This condition occurs even if the arc length is correct but the arc is advanced too rapidly. For correct arc-welding machine settings, see Table XIII.

The *porosity* is caused by blowholes which are formed while the oxygen of the air is in contact with hot metal. The air is expanded under heat and is lighter in density, rising in the molten puddle when oxygen unites with the gas-forming elements in steel such as carbon, carbon monoxide, and carbon dioxide, so that they escape from the molten mass. Minute holes remain because the metal is too plastic to close the gas exits. The action of steam escaping from boiling water is similar, except as the steam vapor leaves the water surface the fluidity of the water causes the opening to close. Gas which does not escape from the metal is retained in cavities. Since gas holes weaken the steel, the conditions promoting them should be avoided. Flux-coated rods, correct arc length, and proper handling of the electrode at proper current keep fish-eyes (so-called because hydrogen gas *bubbles* with *cracks* appear like a slit-eye) and blowhole formation at a minimum.

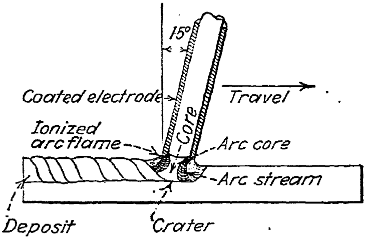


FIG. 77.—Elements of metallic arc. Backward welding technique.

111. Flux-coated Rods.—The purpose of a flux coating on the electrode is to produce, under welding heats, an ionized atmosphere which reduces arc resistance. The materials which serve this end are compounds of calcium, barium, lithium, and sodium. Suitable methods of compounding these materials assist in making clean welds. *For airplane-repair welding the flux-coated rods produce more satisfactory welds than does the bare electrode.* There is a saving in electric power with the coated rod as well as a possible variation in arc length without detriment to the weld.

112. Protection in Arc Welding.—The most important protection from the arc rays and to the eyesight is the *welding helmet* (see Fig. 78). *The ultraviolet and infrared rays not only produce eyestrain and burns but skin burns when exposure is indiscriminate and there is no protection.* Helmets and hand shields are equipped with special lenses which protect the eyes from harmful arc rays. Helmets of better design provide additional protection to head, neck, and face. *Under no circumstances should goggles intended for gas welding ever be used for viewing the arc, since these lenses do not eliminate the harmful arc emanation.*

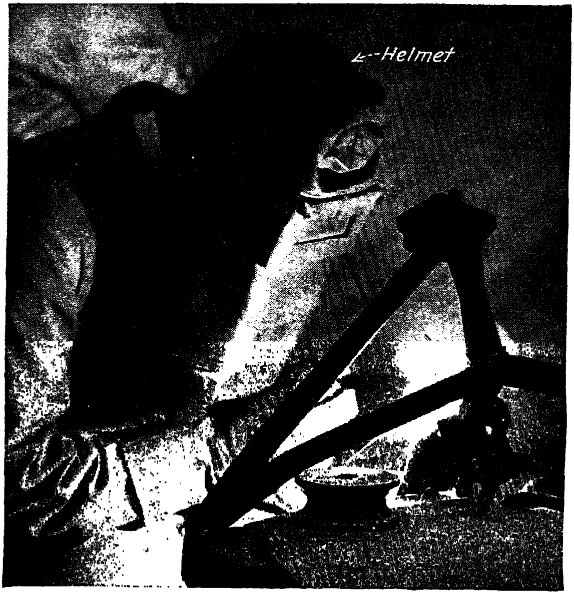
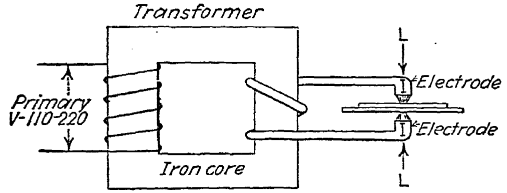


FIG. 78.—Arc welding of landing-gear strut. (*Courtesy of Boeing Airplane Company.*)

113. Resistance Welding.—One method which furnishes a means of speeding production for special parts (Fig. 80) and repair of struts, fittings, instrument boards, and radio chassis is *resistance welding*.

Two methods of utilized, namely, *spot welding* and *flash welding*. *Spot welding* is produced by the passage of electrical current of great amperage and low voltage through adjoining surfaces under external compressive pressure (Fig. 79). In *flash welding*, the consolidation of adjacent metals is accomplished in three steps. *First*, the metal is subjected to a light external pressure between suitable electrodes. *Second*, the adjoining metals are separated microscopically and arcing occurs. *Third*, the weld is completed by application of heavy pressure which throws out the molten metal and oxides to form a fin or flash while fusing the mating surfaces of the metal which is left without detrimental oxides.



L = Electrode pressure, 250 to 1,250 lb.
L = Current 11,000 to 35,000 amp.

Fig. 79.—Resistance-welding circuit.

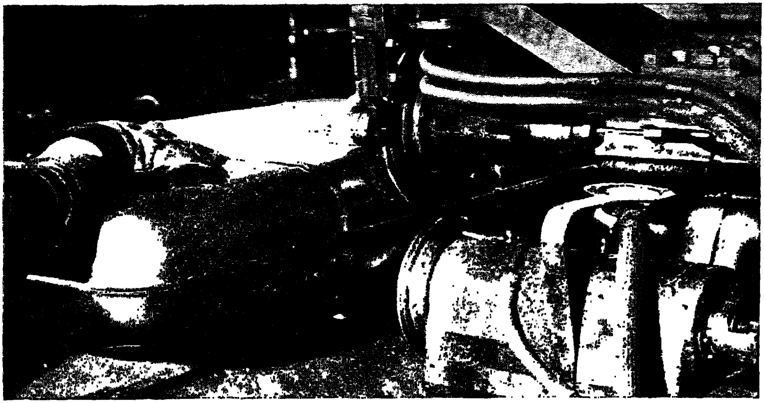


FIG. 80.—Seam welding of gasoline tank. (*Courtesy of P. R. Mallory and Company.*)

Both types of resistance welders usually operate on alternating current. For resistance welding a typical circuit appears in Fig. 79. The power passes through the primary coil which is wound on a continuous laminated soft-iron core. The flow of the alternating current produces pulsating magnetism in the iron core, which energizes the secondary winding of a few turns, developing a large output at low voltage. The secondary leads are extended to the electrodes wherein is clamped the work to be welded.

In the *flash-welding unit* the power is interrupted momentarily when the parts to be welded are separated. This produces a high voltage at the weld, and the arc across the small gap generates enough heat to melt the adjacent surfaces. During the last operation these surfaces are forced together by mechanical linkages, and the molten steel is congealed in one continuous weld, the surplus metal being squeezed out (Fig. 81). This surplus metal or flash is trimmed to a flush position in the completed joint. *During flash welding, goggles must be worn as protection from hot particles and glare from the arc.*

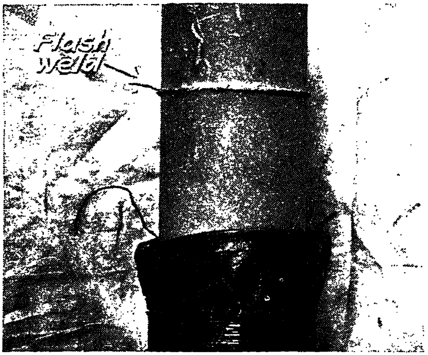


FIG. 81.—Tail-wheel strut. Flash welded. (*Courtesy of American Welding Journal, September*, 1936.)

Review Questions

1. What is the maximum safe torch pressure of dissolved acetylene? Why?

2. How is acetylene safely transported at pressures as high as 235 lb. per square inch?

3. Why is the acetylene tank for dissolved acetylene filled with an inert and porous material?

4. Why is hydrogen used in aircraft welding?

5. How are oxygen tanks, regulators, and manifolds protected from excessive pressure?

6. Where would a welder stand at the regulator when turning on oxygen? Why?

7. With the oxyacetylene-torch valves closed, what gas is lighted first? What occurs if the other torch valve is opened first?

8. Give a brief explanation of how to shut off the gas-welding equipment when the welding job is finished.

9. Describe a neutral oxyacetylene flame. An oxyhydrogen flame. What are the maximum temperatures of these flames?

10. In an oxyacetylene flame, why is the outermost, or third, zone of the flame mildly oxidizing?

11. What are the causes of an overheated tip? What are the results of an overheated tip?

12. Why is a wire brush an important piece of equipment for oxyacetylene cutting of steel?

13. What is a flashback? What is the effect of a flashback on the torch? What should be done after a flashback?

14. How is an acetylene leak located? An oxygen leak?

15. Explain briefly what happens in a stem-type regulator when the torch attached to it is shut off with a previous low-pressure reading of 25 lb. per square inch. Use a sketch to assist in making a clear explanation. How does the regulator function if the torch valves are opened?

16. Name the kinds of electric welding used in airplane repair.

17. Describe the process of spot welding. Show the circuit required.

18. Show the essential details of the metallic arc.

19. Illustrate the direct-current arc-welding circuit. Indicate the polarity of tubing when welding with a bare rod.

20. When is burning used in aircraft production? How does the burning tip differ from the welding tip? Why?

21. What is a flux? When is it used in welding? Name three ways in which flux functions to prevent unsound welds.

22. When should welding goggles be used during welding?

23. Should goggles for gas welding be used for arc welding? Why not?

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Questions for Thought and Study of References

1. What are the reasons for creeping of gauges? Outline the procedure in correcting the creep in gauges. (Refs. 5 and 9.)

2. What precautions are to be observed in handling, using, and storing oxygen cylinders? Acetylene cylinders? (Refs. 1 and 2.)

3. Describe the operation of the Linde oxygen-tank valve. (Ref. 1.)

4. By what method are leaky torch tips determined and remedied? (Refs. 5 and 9.)

5. Under what circumstances should extra welding equipment be available? (Refs. 5 and 6.)

6. State the variables in resistance welding which must be accurately controlled. (Refs. 8 and 10.)

7. How does a stabilizer function in an arc-welding circuit? (Ref. 3.)

8. State the three known methods for protecting the transfer of metal by means of electrode coatings. (Ref. 6.)

9. How does the corrosion resistance of bare-rod welds compare with shielded arc welds? (Ref. 6.)

10. Prepare a table of the combination of unlike metals which are used in airplane construction and can be welded by the resistance method. (Ref. 10.)

11. Name the adjustments required in the spot welding of high-tensile stainless steel. (Ref. 14.)

12. What limits exist in the resistance welding of aircraft alloy S.A.E. X-4130? (Ref. 15.)

13. In what respects is flame processing a more rapid and efficient method than machining operations? (Ref. 12.)

CHAPTER VIII

AIRCRAFT WELDING METHODS

The metal most extensively welded is *steel* of the kinds which are outlined in Chap. V. Therefore *steel* is of particular interest, in airplane maintenance, to the welder. Although *aluminum and its alloys* are becoming of first importance in the metal airplane, welding of aluminum in thin gauges by *gas* or *arc welding* is unsatisfactory for structural parts. *Resistance welding* furnishes the most promising method for fabricating thin-gauge aluminum and stainless steel.

114. Effects of Welding Heat.—All metals are sensitive to heat; that is, their properties are changed readily by heating. *In fact, the agency of heat is necessary to develop new and valuable properties which are not available in the metal as received.*

The *weld* is a small steel ingot deposited at the interfaces of the adjacent plates. The method by which this deposit is made establishes the properties of both the metal in the weld and the abutting areas. The principal changes which occur are revealed in a polished and chemically etched section of the affected areas.

115. Examination of Welds.—While the physical tests, such as for *tensile strength, hardness, ductility,* and *toughness,* are important, they cannot be relied upon to reveal the *cause of variations* in these properties. Only by examination of the welded structure in section is the true cause and means of correcting any variations determined. If it is impossible to spare a part of the welded repair for this examination, a separate counterpart can be welded under identical conditions existing at the time of the repair weld.

This specimen is prepared for examination by *shearing* or *sawing* across the weld (as noted in Chap. VI), *grinding* progressively with a fine abrasive wheel, finest grade of emery cloth, and finally with 000 French emery paper. Then the specimen is *polished* on rotating canvas and broadcloth wheels, on which water with jeweler's rouge and magnesium oxide in suspension is sprayed. The final surface should have a mirror finish; and after *cleansing* in alcohol and *drying*, it is ready for the *etching* solution. A steel weld, when etched for 5 sec. with a 5 per cent nitric acid and 95 per cent ethyl alcohol solution, shows to the naked eye the presence of *blowholes* and *impurities* in darkened areas, and the *amount and depth of fusion.* The most important indication is the *zone* affected by welding. By measuring the original gap between the plate edges (Fig. 82) before welding and comparing the affected area (Fig. 82), a judgment can be made of the *amount of fusion. The fusion of a good weld should average in total width three times the original gap in order to taper the strength of the plate into the weld.*

This method provides the means of determining wherein welds are deficient and the possible ways of remedying the welding operation.

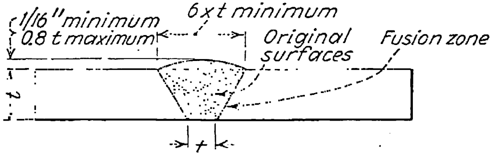

FIG. 82.—Proportions of typical aircraft weld.

It is possible to examine aluminum welds in a similar manner except the most effective etching reagent is 10 per cent caustic soda (NaOH) and 90 per cent water when applied to a dry polished surface of the welded areas for 5 sec. followed by rinsing and drying. This solution is usually available in the propeller-repair station.

The *Magnaflux method* (Par. 77) is useful for detecting defects, but it is unsatisfactory for determining the amount of fused area in a weld.

When *X-ray equipment* is available, it is possible to determine weld defects and fusion. (See Fig. 83.) It requires the services of trained X-ray technicians to make interpretations of X-ray films which have been properly exposed and developed.

116. Elements of Welding Metallurgy.—The method of studying the alteration of metal composition in the weld deposit and adjacent metal is provided by *metallurgy.* This term is used in a restricted sense because the concern is with the effects of heat in plastic and solidified steel. Considerable difficulty is encountered in the metallurgical study of these changes since all temperatures from liquid to solid state exist during the deposit. *It is necessary for the airplane welder to know both the correct and detrimental factors which are produced during the welding process either by gas, electric-arc, or resistance methods.*

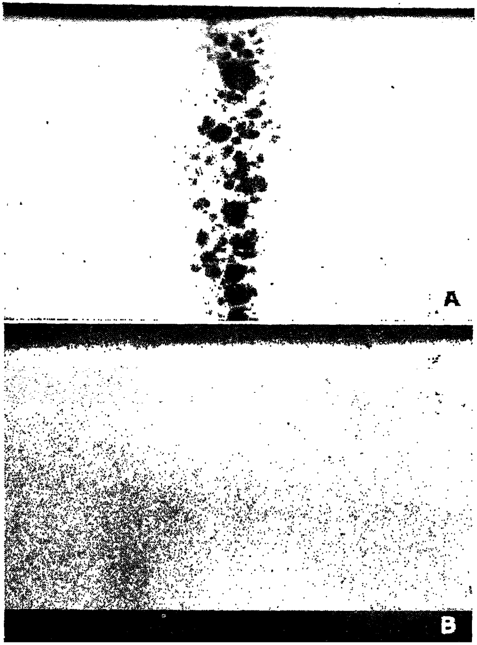

FIG. 83.—X-ray study of weld. Radiographs of two welds made by the same individual, with two different welding methods. The fact that one shows as a perfect weld proves that with a given method one may become skilled when the x-ray is used as a means of developing a correct technique. (*Courtesy of General Electric X-Ray Corporation.*)

In general the welding heat produces excessively large grain in the weld. This grain tapers in size to the original grain at a distance of twice the weld width either side of the weld, when the proper torch adjustment, gas pressures, and handling are used.

In the welding operation oxygen and nitrogen are usually present in the convection currents of the air surrounding the heated weld. *At the higher temperatures, iron reacts with oxygen* *more readily, resulting in oxide formation with an embrittling effect on the surface of the weld.* It is under this layer that true carbon steel exists since the oxygen also combines with the carbon in the steel at the surface. With more volatile metals such as *molybdenum* the reaction with oxygen in sufficient quantity causes the evaporation of this metal which is used to maintain the fine, tough grain in steel. *Every step in welding, therefore, requires suitable protection from oxygen and nitrogen contamination.* In a gas flame, at the end of the inner zone, the atmosphere is *reducing,* and therefore the position in which it is held furnishes the necessary protection (Par. 102). The remainder of the protection is furnished by the welding rod.

117. Part Played by Welding Rods.—The low-carbon-steel welding rods formerly used on welded construction have important bearing on the method of welding and condition of the finished weld.

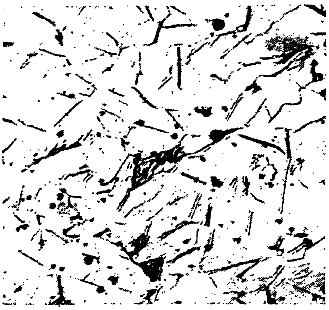

FIG. 84.—Steel with nitrides present. Magnification 75 ×.

Briefly, the *only method of eliminating the iron oxide* from the weld is to increase the temperature of the weld deposit above the melting point to produce a fluidity necessary to float it out. This oxide, which dissolves in metal, has a reaction with the carbon which forms blowholes. Only by keeping the carbon content of the rod low is the reaction avoided, and by a high degree of skill is the weld made sufficiently strong.

Recently rods have been devised which *minimize the reaction between the iron oxide and the carbon.* At least the products of the metallic reactions are solid and become fluid at lower temperatures than the pure metal deposit which readily finds its way to the surface of the metal deposit. Here it serves three purposes:

1. To cleanse the weld metal.
2. To form a protective coating against further oxidation.
3. And to lower the melting point and produce a free-flowing deposit.

By this means the carbon content has been increased so that the strength of the deposit approaches that of the original plate or tube.

Welding rods for electric-arc welding instead of having the principal elements compounded with the electrode, are provided with a flux coating which contains elements which cleanse the weld by preventing contamination of iron scale and other impurities.

Specimens of unsound welds and better types of weld structure are shown in the accompanying figures. In Fig. 84 is shown a *porous weld* with *oxide inclusions* and *blowholes.* It is obvious that these oxides are brittle and lower the strength below that obtained by correct welding procedure. In Fig. 84 appears a weld with *nitride* and *other inclusions.* The nitride needles appear crosswise of the intercrystalline grain boundaries. *The presence of these nitrides reduces grain strength, ductility, and fatigue resistance* in the presence of iron oxides or their inclusions. Only by the use of reducing atmosphere which acts as a protective film can oxide and nitride formation be reduced.

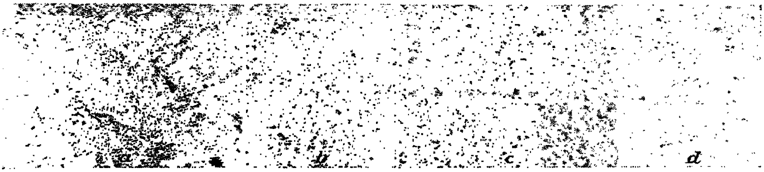

FIG. 85.—(*a*) Weld zone; (*b*) transition zone; (*c*) annealed zone; (*d*) original metal.

A typical weld of excellent physical properties may be seen in Fig. 85. The tapering of the weld-grain size to that of the original plate is readily seen.

118. Additional Effects of Welding Heat.—Where the chemical composition of the weld remains uncontaminated, two conditions are always present: (1) Excessive heat; and (2) temperature or thermal stress resulting from shrinkage of the weld.

1. *Excessive heat* which accompanies the welding of steel produces excessive enlargement of the steel grains. This is known as *grain growth* and is only partially controlled in the welding process. It usually remains for further heat treatment to adjust the different grain sizes. Since large grains fracture under load more readily than the small-sized grains, *the large grain definitely is a liability in aircraft repair.* The torch may be successfully used by reheating the entire weld to a bright red heat, allowing it to cool in air. Prolonged heating at this temperature should be avoided since grain growth will occur.

The heat of the torch permits a ready means of relieving the stresses due to shrinkage from the fluid weld to the solid deposit.

2. The *thermal stresses* constitute an internal loss of strength. For example, a metal bar, which is fastened at its ends, similar to the condition approached when certain aircraft members are welded in jigs, is prevented from expanding or contracting. The effect is the same as when the bar has been compressed the distance equal to the expansion under the welding heat, or has been extended a distance equal to the shrinkage of the heated piece after it has cooled. *These losses in physical strength are due to an equivalent elongation or contraction of the metal, varying in amount with the temperatures.* If the weld is deposited at a temperature of 2900°F. and the original plate metal is at 1450°F., the weld will shrink twice as much as the original plate. For purposes of welding, it is evident that *the metal at the juncture where there is a temperature difference must yield sufficiently to compensate for the contraction.* When this shrinkage is confined to a very limited area, it is relieved by fissures or incipient cracks.

Failure is necessarily hastened by this condition. Only by means of *stress relieving,* which is accomplished by heating the weld and adjacent areas to a dull-red heat, allowing them to cool in air, can these fractures be prevented. Often the stresses may be relieved by hammering the weld, while it is still hot, with a ball pein machinist's hammer. Fluxing rods assist in preventing rapid cooling of the weld and possible cracking, by reason of their slow cooling effect.

This *mechanical shrinkage* appears in other ways, principally in *distortion* or *warping* of the welded member. In an elemental manner this can be shown in Fig. 86*a*. When a plate is heated on its upper surface while the lower surface is kept cool, we have a condition similar to a weld bead being laid on a plate. The following changes take place: After the plate begins to cool, the under side contracts slightly but the upper side, which is at a higher temperature, shrinks the greater amount since it cools from a higher temperature than the lower side. The total shrinkage therefore shortens in a line parallel to the original surface, giving rise to the general principle that *the hot side, when cooled, becomes the shorter side.* In plate and tube welding this distortion requires adjustment. For example, in a fuselage where tubing is replaced it is necessary to reheat the weld bead and apply heat on the opposite side of the tube to counteract

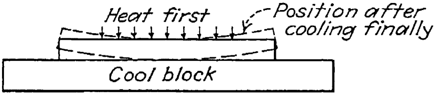

FIG. 86*a*.—Shrinkage of plate alternately heated and cooled.

the shrinkage. For example, the tee weld Fig. 86*b*, when prevented from motion to adjust the shrinkage, is relieved by bending the tube in the manner shown by *a-a*. *If the stress at any point exceeds the stress of the weld material or the tube, surface cracks develop to relieve the thermal stress.*

Application of heat to *cold-drawn steel wires* or *copper tubing* is to be done sparingly, because it not only reduces the yield strength but also develops warpage when the heat is not uniformly applied. This *annealing* or softening requires a little time, and therefore it is possible to prevent loss of strength and distortion by applying and withdrawing the heat quickly.

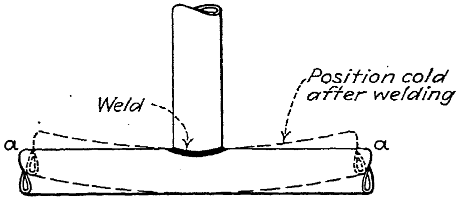

FIG. 86*b*.—Tee-weld shrinkage.

In *arc welding* these effects of thermal stress must be adjusted by the proper use of flux-coated rods or subsequent heat treatment or peining.

119. Considerations for Making Sound Welds.—The procedure by which sound welds are produced involves consideration of the following factors:

1. Application of heat.
2. Alterations of rod and base metals.
3. Judgment of the welder and user.
4. Design.

1. *Application of Heat.*—The amount of heat which is applied during welding is determined by the use of the proper tip size and gas pressures, which are given for different thicknesses in Table XI; or, if electric welding is used, by the proper regulation of voltage and current for the thicknesses of metal, as given in Table XIII.

The position of the flame or arc must be controlled by directing the source of heat at the intersection of the metal plates so as to obtain uniform deposit on each of the mating surfaces. Either *forward*[1] or *backward* welding may be used in depositing the base metal, with equally effective results. Sufficient *penetration* is obtained with the proper position or temperature of the gas flame or arc, and the proper *direction of travel,* to produce an even contour in the fusion zone for the entire depth of the plate.

The *bead should be proportioned* so that it is symmetrical with the axis of the weld and without excessive reinforcement, which leads to an early fatigue failure and excessive weld strength. The bead has reinforcement and contour in its final deposit, according to that shown in Fig. 82 for plate welds and in Fig. 106 for plate-to-tube welds.

The *adjustment of thermal stress is necessary to produce a welded structure of uniform physical properties.* The usual method of compensating for, or adjusting, these thermal stresses is by using the torch in heating the weld, followed by a localized heating on the surfaces opposite the weld. This practice, if not prolonged by excessive heating, usually maintains the alignment of parts. In complicated structures such as cluster welds more thorough and more uniform adjustment of thermal stresses is obtained by the heat treatment of the entire welded structure, if this procedure is convenient.

2. *Alteration of Rod and Base Metals.*—The *degree of contamination* in a weld is controlled by the *manipulation* of the filler rod, the *position of the flame* or arc relative to the weld, and the *quality of the filler rod.*

When the oxyacetylene flame is used to heat and weld in the outer zone (Fig. 72*b*), heating is slower and accompanied by oxidation of the plate metal, producing gases and solid inclusions or "cold shuts." The oxyacetylene flame must be used where the temperature is greatest and the protecting zone is most effective, namely, at a position $\frac{1}{16}$ in. from the tip of the inner zone (Fig. 72*b*).

Similarly, the arc flame must be used so that the arc length from rod end to crater (Fig. 77) does not exceed $\frac{1}{8}$ in. A longer arc permits contamination by air, and oxidation of the weld. An arc length which is correct will produce similar results, *if the rate of travel is too rapid.*

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[1] By *forward welding* is meant that the rod position is maintained ahead of the torch flame or the arc in such a manner that the rod is deposited in the open seam ahead of the torch or arc and welder. *Backward welding* consists in holding the welding rod behind the advancing flame or arc in such a way that the heat is between the welder and the deposit so that the seam is open between the deposit and the welder.

The metals must be free from defects of rolling or cold-drawing and chemical impurities. This is only possible when *clean, sound metal* is used in repair sections. *It is never advisable to use cheaper metals* because of their unsatisfactory welding properties and deficient physical properties.

Corrosion.—Corrosion is an important consideration in welded repair sections. Carbon-steel welds do not possess corrosion-resisting properties.

The following procedure in repaired tubes or plates is necessary to protect the repair from deterioration: Since the original treatment of the steel in welded structures required a coating of enamels, varnishes, or dopes, *repair welding cannot be undertaken satisfactorily until these finishes have been removed.* Their presence during the welding embrittles welds, making them very susceptible to corrosion.

It is not absolutely necessary to remove cadmium plating from steel parts before welding. For large parts, it is only necessary to remove the finishing coats around the area to be welded by applying paint remover with a small brush or rag. After the paint is softened, it may be scraped off with a dull-edged knife or scraper. The area cleaned in this manner should extend far enough beyond the area to be welded so that the paint remaining cannot be burned, since burned paint is more difficult to refinish satisfactorily. *All paint remover should be washed off with hot water.* Where plating is removed by very fine steel wool or emery cloth, care must be exercised to prevent excessive rubbing, which reduces the thickness of the part or leaves detrimental scratches.

After the welds have been completed, scale and accumulations should be cleared by sandblasting or wire brushing. These surfaces may then be refinished with one coat of metal primer and two coats of enamel.

If repaired section is to be plated, the instructions of Job Unit 3 should be followed.

Closed tubes or hollow steel parts should be filled with hot raw linseed oil and drained through drainholes drilled at a point six times the width of weld bead from the weld. After draining, the holes are plugged with self-tapping or drive screws to keep out air and prevent corrosion on the interior of the hollow parts. This hot-linseed-oil treatment serves to drive out the moisture, which inhibits corrosion, and to form an elastic film on the interior surfaces.

For *stainless steel,* which is welded with a gas flame or an electric arc, a stainless-steel welding rod which has been treated with *titanium* or *columbium* is required to stabilize the weld deposit against corrosion.

For *aluminum welding,* a suitable flux (Par. 100) must be used to insure a sound deposit. These fluxes are corrosive, if left on the weld, so it is necessary to wash all traces of them off after welding, according to the method prescribed in Par. 128.

Where *soldering* of aluminum and stainless steel is done, similar precautions must be taken.

Brazed or soldered joints should not be reheated since these metals in fused steel imbrittle it and hasten corrosion.

3. *Judgment of the Welder and User.*—Repairs of welded structures are required for tubes or parts which have been dented or bent. Since these are results of impacts or overloading, care must be exercised in correcting the damage. Typical repairs for compression members, tension members and other damaged parts are described in Par. 139.

Much of the success in making successful repairs depends upon the use of the correct welding procedure and experience in making these typical repairs. The principal repairs of damaged sections are outlined in job units of Chap. VIII.

120. Causes of Repair Failures.—After the damaged parts have been repaired in accordance with the requirements of the Civil Aeronautics Authority or the U. S. Army Air Forces (Par. 139), whichever applies, reliable inspection technique must be used. The *value of this inspection* is determined very largely by the *degree with which conditions contributing to the premature failure are detected,* the important ones being:

1. *The care and precision* with which the repair is done, that is, the handling, adjusting, forming, and checking of the materials used. Proper tools which are kept in good condition should be used.
2. *Proper alignment of parts* by suitable fixtures which prevent undue expansion and contraction of the heated parts. If expansion or contraction at ill-fitted points exist, surface cracks usually are evident.

3. *Excessive heats* usually show evidence of burned metal, which is brittle and unsound. *Undercutting* at the sides of the beads is another evidence of excessive temperature of either the flame or the arc.

4. *Insufficient heat* is evidenced by overlap and excessive bead reinforcement.

5. The *appearance* of the weld bead, if porous, is usually due to an *oxidizing flame* or, under certain circumstances, a *reducing* or *carbonizing* flame. Such welds must be redone. When the arc deposit is examined, porosity is caused by a long arc or excessive speed of electrode travel. These welds are unsatisfactory.

6. *Excessive reinforcement of the bead* leads to early fatigue at the juncture of the bead of the plate or tube. Undercutting at the juncture of the bead of the plate or tube has low fatigue resistance. (See Fig. 59, Chap. VI.)

7. *Scratches or tool marks* in surrounding areas or in the weld bead itself lower the fatigue resistance at these points. These defects, if not deeply impressed, can be cold rolled to improve fatigue resistance.

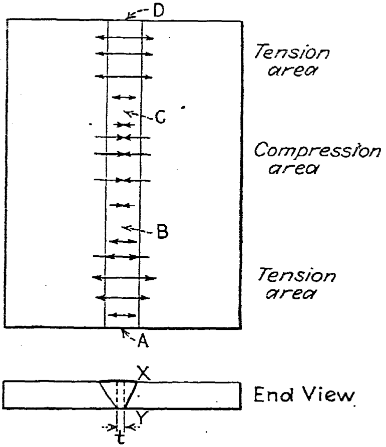

FIG. 87.—Showing tension and compression areas in seam weld. Tack welds at *A*, *B*, *C*, and *D*.

Repair sections require accessibility without sacrificing the allowance for the adjustment of thermal stresses. Minimum distances from nearest tubes and plates are shown in typical sections in Fig. 96.

In tube clusters, stiffness may be added in the joints by use of gusset plates similar to Fig. 95. These gussets should not be welded in positions where they would be subject to torsion or twisting. Prestressed members, such as cold-drawn wire tie rods or fuel lines, and axles should be heated sparingly to prevent loss of strength. Hard soldering (Par. 137) is recommended where the strength of these parts must be preserved.

121. Some Fundamental Welding Facts—Shrinkage and Warpage.—A few fundamental facts regarding welding of joints may be cited as a guide in repair. Provision for *distortional effects of welding heat* requires primary consideration after the correct size of the member to carry the load is fixed upon with provision for lowered joint strength. In Fig. 87, the two plates, during welding, move together at the end opposite to where the weld has commenced (at A) with a gap of t thickness, causing the two plates to contract as the bead solidifies and closing the gap to less than t at C. If the effects are analyzed carefully, it is evident that the bead, when laid progressively from A toward C, undergoes localized stresses represented by tension and compression.

As the weld is started at A and laid in the direction of C, the hot metal cools and contracts, which produces a state of tension. The adjustment of this tensile stress can be obtained only by the plates moving more closely together. When the bead between A and B exceeds the amount of hot metal deposited, the hotter metal remains under compression, since the colder metal contracts faster than the deposited metal. *The bead remains in compression until the compressive strength of the completed deposit between B and C equals the tensile strength of the metal contracting.* Then this compressed metal deposit between B and C becomes more rigid, since it is gradually cooling. The hot-metal deposit having greater ductility contracts more than the colder metal beyond C, hence the bead to D continues in tension since it is the final portion of the weld to shrink in a seam already cooled and rigidly set.

Although this analysis applies to a weld in a plate, it is also true of a tube whose circumference is equal to the length of $2\pi r$, where r is the radius of the tube. *The areas in tension, when the shrinkage exceeds the tensile strength, will rupture.* The portions subjected to compression ultimately buckle or wrinkle with consequent difficulty in maintaining alignment. By the use of tack welding or localized deposits at points A, B, C, and D, which are spaced equidistantly, the compression areas are localized sufficiently to prevent the origin of *buckling stresses* and consequent *warpage* or *wrinkling.* Further warping may be introduced by heat not conducted evenly from surfaces X and Y. When the surface X cools more rapidly than surface Y, the surface Y shrinks last, thus inducing stresses of higher intensity of the weld on surface X. Adjustment of these conditions may be accomplished in several ways.

When properly spaced tack welds must be relied upon to reduce the shrinkage in the seam, then there arises the need of providing equal cooling on opposite surfaces. On the weld surface, the temperature is sufficiently high to cause rapid cooling, while on

TABLE XI.—TIP SIZES FOR OXYACETYLENE WELDING OF STEEL

Metal thickness		Tip size in drill number		Pressure, lb. per sq. in.			
				Oxygen		Acetylene	
Gauge	Inches	Low-pressure torch	Balanced pressure	Low	Balanced	Low	Balanced
28	. . .	63	77	9	1.5 to 3	4	1.5 to 3
22	$\frac{1}{32}$	61	68	10	1.5 to 3	4	1.5 to 3
16	$\frac{1}{16}$	57	62	10	1.5 to 3	4	1.5 to 3
13	$\frac{3}{32}$	56	57	11	1.5 to 3	5	1.5 to 3
11	$\frac{1}{8}$	55	55	12	1.5 to 3	5	1.5 to 3
$\frac{3}{16}$	. . .	52	53	14	1.5 to 3	5	1.5 to 3
$\frac{1}{4}$	. . .	50	50	16	1.5 to 3.5	6	1.5 to 3.5
$\frac{3}{8}$	. . .	47	44	19	2 to 4.5	6	2 to 4.5

NOTE.—For aluminum welding, brazing, and hard surfacing, the next larger drill size of tip than that specified for the same thickness of steel is used without changing the pressures. For example, to weld aluminum, braze, or hard-surface steel, ¼-in. thick tip with 47 drill size and oxygen pressure of 16 lb. per square inch and acetylene pressure of 7 lb. per square inch would be used for a low-pressure torch; or, 44 drill size tip at 1.5 to 3.0 lb. pressure for balanced-pressure torch.

These tip sizes are for the Presto-weld torch, W-105, with the same mixer for all tip sizes.

TABLE XII.—TIP SIZES FOR ALUMINUM WELDING WITH OXYHYDROGEN FLAME

Metal thickness, gauge	Tip size diameter of orifice in tip, in.	Pressure, lb. per sq. in.	
		Oxygen	Hydrogen
22	0.025	1	1
20	0.035	1	1
18	0.045	1	1
14	0.055	1	1
12	0.065	2	1
8	0.075	2	1
5	0.095	3	2

From "Aluminum Welding," p. 7, Aluminum Company of America, 1936.

the opposite surface it becomes necessary artificially to cool it by wet asbestos in flat plates. *In instances where the plates welded are of entirely different thicknesses, cooling of the side opposite to the weld surface is accomplished by keeping the plates in contact with a good heat conductor such as a heavy iron plate.* Where the interior surfaces are not accessible, light gauge metals consistant with the strength requirements of the repair should be used because these cool rapidly in air throughout the thickness.

122. Warpage in Magnesium and Aluminum Welds.—For metals which are brittle at welding temperature, such as magnesium and aluminum in which the contraction is nearly twice that of steel, the joint is made flexible to absorb shrinkage. The usual methods involve the *notching of plates* on the edge of the seam or *flanging* the adjacent edges, with such refinements as *crimping* the surface parallel to the seam to be welded.

These elaborate precautions are not possible with tubing except by tacking at three or four equally spaced points to maintain the alignment of the adjacent tubes (Fig. 105). The abutting surfaces must be separated equally throughout their circumference.

123. The Application of Welding Heat.—The initial step in welding is to set up the equipment; that is, the connecting of oxygen and acetylene or hydrogen with the proper torch. The torch for oxyacetylene welding should be fitted with a tip of the proper size for the thickness of metal being welded (see Table XI). For oxyhydrogen welding, the torch should be fitted with a tip for the gauge of aluminum being welded (see Table XII). The oxyacetylene flame and oxyhydrogen flame should be adjusted to the *neutral flame. Under welding conditions, the flame should be constantly checked for this neutral adjustment.* Carbonizing or reducing flames produce hard, brittle welds while an excess of oxygen produces porous, scaly welds.

When welding with a flame, preheat a limited area at the point where the weld is to be started and bring this point to a sweating heat over an area at least ⅛ in. in diameter. Introduce the welding rod into this puddle in such a manner that the *rod is never directly in the flame* but is behind the tip of the inner zone of the flame in the *backward welding* or in front of the tip of the inner zone of the torch in *forward welding.* After the weld puddle has been established, the rod will melt at the proper rate when kept entirely in this puddle.

The basic methods outlined in the previous discussion remain invariable for all types of welding; such as downward welding where the plate is beneath the welding flame, or in a welding position where the flame must be moved over the seam, and in overhead welding where the flame is beneath the plate. In the latter instance the puddle is prevented from dripping by manipulating the torch so the heat is alternately applied and slightly withdrawn by upward and downward oscillation of the torch flame.

124. The Use of the Electric Arc.—The heat of the metallic arc is obtained by striking a metal electrode against the plate to be welded and slightly withdrawing until the arc length is approximately ⅛ in. The setting of the direct-current or alternating-current welding equipment for a given thickness of metal should be in accordance with the direction in Table XIII. *After the arc is started, move the rod downward toward the work* (*Fig.* 76) *at a uniform rate to supply the metal being fused with the plate.* When the feed of the rod is too slow, the gap becomes great enough so that the arc extinguishes itself or allows contamination of the weld deposit. On the other hand, if the arc is held in a short gap by a rapid feed of the rod toward the plate, the bead would accumulate without sufficient penetration or fusion with correct current setting. Excessive welding currents which are greater than those specified in Table XIII result in serious *undercutting* and *depreciation of the strength* of the joint. For currents lower than those specified in Table XIII, penetration and fusion are insufficient for a satisfactory weld.

TABLE XIII.—CURRENT AND ELECTRODE SIZES FOR METALLIC-ARC WELDING OF STEEL

Thickness	Electrode diameter, in.	Welding current, amp.
20 gauge	1/16	10 to 25
18 gauge to ⅛ in.	1/16	20 to 40
⅛ in.	3/32	30 to 60
3/16 in.	⅛	50 to 100
¼ in.	5/32	75 to 150
⅜ in.	5/32	150 to 200

Absorption of the arc heat by iron scale, paint, oil, and moisture accumulations on the surface tends to extinguish the arc. Only by removing these impurities by grinding, sandblasting, wire brushing or scraping the surfaces can a stable arc and a sound weld be obtained. The better welds in arc welding are obtained in either downward welding or overhead welding, the rod being positioned nearly perpendicular to the work (Fig. 77).

The rules for seam spacing and adjustment of thermal stresses are similar to those outlined for gas welding.

The correct combination of *welding current* (consult Table XIII), *speed of travel,* and *rate of electrode feed* produces a sound weld without evidence of *blowholes, porosity, undercutting,* or *overlapping* of the weld bead. The penetration should be to the full depth of the seam. Larger welding currents than necessary result in larger areas of fusion and consequently large-grained steel and excessive shrinkage, which can only be relieved by incipient cracks within the weld.

Tack welding should be done in the same manner as discussed in gas welding. The minimum spacing of the plates or tube should be used to prevent excessive warpage; 1⁄16 in. represents a good spacing. When either plates or tubes are of different thicknesses the electrode is tilted slightly toward the thicker of the two metals which supplies sufficient reflected heat to fuse down the lighter metal at the proper rate. *Care must be exercised in finishing a weld to shorten the arc and prevent arc blow, which burns the final deposit.*

125. Aluminum Welding.—The basic welding method for aluminum is identical for sheets, plates, and tubes. It remains for a particular design of joint to modify such factors as preheating and adjustment of temperature stress. The most important requirement in gas welding is the use of a slightly carbonizing flame (in acetylene welding) or reducing flames (in hydrogen welding). *An oxidizing flame produces detrimental aluminum oxide and a resulting weld of poor quality.* The flame adjustment should be made to produce a soft flame free from excessive tip pressures. This flame is usually obtained by using one torch-tip size greater than that used for welding steel for equivalent thickness (Table XI). An aluminum flux must be used to obtain sound welds. *One of the most satisfactory fluxes* is Navy Specification 51-F-2A consisting of 32 per cent sodium chloride, 24 per cent potassium chloride, 24 per cent lithium chloride, and 20 per cent sodium fluoride. All of these compounds are designated by weight percentage. Care must be exercised in preventing contamination of the flux.

Since there is no evidence of color in aluminum at welding heat and since aluminum is very soft and weak, it is necessary to support the seam.

When welding with the torch, the angle of the torch with the plane of the weld should be 30 deg. so as to avoid blowing holes in the hot metal. The inner zone of the flame should be kept at a distance ⅛ in. from the metal surface. Fusion is rapid and requires rapid passage of the torch flame or movement of the plate under the torch in order to prevent burning through or excess oxidation. *When any weld section is faulty, it becomes necessary to chip out the old metal and reweld with new metal.*

When the work is started, the two edges should be brought to a plastic condition before the weld is started. The correct time of introducing the welding rod is quickly learned by the operator so that only a small portion of the metal remains molten at any position of the flame. Where the metals to be welded are not free to contract, an aluminum welding rod containing 5 per cent silicon, which absorbs much of the shrinkage, should be used.

The *advantages of the 5 per cent silicon rod* in producing welds of high strength and good corrosion resistance are as follows:

1. That it *produces a weld of lower melting point,* and *greater melting range* than a pure-aluminum rod at a much lower temperature, hence thermal stresses are absorbed in the plastic weld instead of producing incipient cracks in the base metal.
2. This composition of aluminum rod is *not brittle* at welding temperatures.
3. The silicon content produces a deposit which *shrinks little* while cooling from welding temperature and permits the rigid mounting of parts and welding jigs.
4. The weld deposit is free from shrinkage and relatively *free from contamination,* producing *ductile* welds.

The features of welded aluminum and its alloys as outlined in the previous discussion remain the same regardless of the shapes and kinds of aluminum which are welded.

Similar conditions of welding of aluminum obtain for arc welding with the usual exception that an arc with reverse polarity and an electrode with the appropriate flux coating are used. The *welding currents* of given thickness are approximately those required for steel (Table XIII) and the *rate of travel* is in the same proportion.

126. Types of Aluminum Joints.—Aluminum sheet of less than 1/16 in. thickness may be butted together during the welding operation. In the presence of suitable flux, the welding rod is then fused into the joint according to the basic method of the previous discussion.

For aluminum sheet greater in thickness than 1/16 in., the edges of the abutting sheet are flanged in accordance with Fig. 112. In welding this seam, flux is supplied on the flanged surfaces and the welding heat applied on span lengths up to 6 in. without tacking or the addition of filler rod.

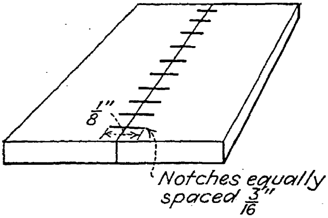

FIG. 88.—Notched butt-type joint for aluminum sheet.

The flange joint is not suitable for arc welding. However, the plain butt joint, or the notched butt joint (Fig. 88) should be used.

When the plate thickness is more than 1/16 in. and less than 3/16 in., the butt joint with edges notched with the blade of the hacksaw or chisel to a depth of not greater than 1/8-in. and 1/4-in. spacing (Fig. 88) is used. These notches serve not only to absorb the flux, but to supply the flexibility for absorbing shrinkage after the weld is made. No preliminary tacking is required in this type of joint.

127. Welding of Heat-treated Aluminum Alloys.—These alloys are used for fittings, engine crankcases, and sundry parts. Repair by welding is limited to a very few of these heat-treated alloys. *Duralumin* sheet is a typical aluminum alloy used in fittings and airplane tanks, and prestressed skinned surfaces. This alloy contains aluminum, copper, manganese, magnesium, and traces of other elements. *If it is necessary to weld duralumin, its properties may be maintained only by subsequent heat treatment.* The method of welding is practically the same as previously outlined for the soft grades of aluminum with the exception that the weld be completed in a single pass, particularly on tanks for holding liquids. Reheating of the metal in the first pass by metal of a second weld layer destroys the *strength, ductility,* and *toughness* of the underlayer, by burning.

The heat treatment of a welded strong aluminum alloy depends upon the alloy in question. The temperature to which the welded parts are heated in a furnace or fused-salt bath (50 per cent sodium nitrate, 50 per cent potassium nitrate) varies from 890° to 970°F. Thorough heating requires a minimum time of 15 min. and becomes greater for larger welded parts. Quenching in cold water follows this heating and soaking period in order to preserve the corrosion-resisting properties of these aluminum alloys. Additional protection against corrosion may be had by painting the repaired part with aluminum bronze in a vehicle of spar varnish or lacquer.

128. Removal of Flux.—The flux used in aluminum welding produces corrosion of the aluminum unless the flux is removed. *The removal of flux constitutes one of the important requirements in welding repair of aluminum.* If steam is available and can be played against the weld, the traces of flux may be removed thereby. A more effective procedure to follow is to wash the areas affected by the weld by a hot solution (100°F.) containing 2 per cent nitric acid and water or a warm solution (80°F.) containing 10 per cent sulphuric acid and water. Application of these solutions is to be followed by rinsing with hot water and scrubbing with a brush for 20 min. *The complete removal of the flux can be determined by a few drops of a 5 per cent silver nitrate and water solution.* Persistence of a milky precipitate is evidence of insufficient washing, and washing must be repeated until the silver nitrate solution remains clear when applied.

129. Repair of Welded Aluminum Oil and Fuel Tanks.—Cracks in fuel-tank shells can be repaired by welding (see Fig. 89*b*). It is necessary to remove all paint coatings for a distance not less than 3 in. from the cracks by the application of a suitable paint remover. Traces of paint remover must be thoroughly washed off with hot water. *Any trace of gasoline fumes or oil should be removed before welding heat is applied.* Steam may be used for this purpose, followed by partially filling the tank with fresh water and shaking for a few minutes. The tank should be emptied and the remaining contents removed by the application of compressed air.

Cracks in baffles must be located by lowering a small mirror suspended on a rod through the filler neck or sump opening. Another, more approximate, method is to strike the tank shell with a block of wood *without denting the surface* until the loose section is located. In the vicinity of this crack or cracks, it becomes necessary to cut an opening in the shell through which the welding may be done. Usually a circular hole suffices, or a square hole with rounded corners may be cut. A small hole (1/16 in. in diameter) is drilled at the end of the crack to stop it from spreading during welding or after the tank is placed in service.

The welding of the cracks is done with the oxyhydrogen flame and a filler rod of the same material as the tank, and containing 5 per cent silicon, if available. Apply suitable aluminum-welding flux, supply enough heat to form a bead on the crack, and progress with the weld from the end of the crack toward the hole drilled in the crack.

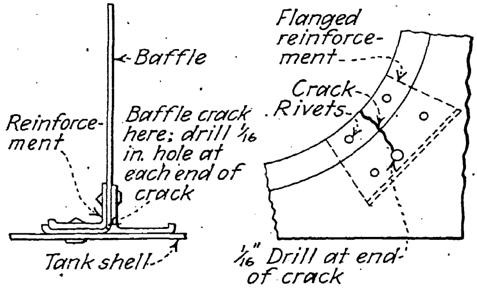
Baffle
Reinforce-ment
Baffle crack here: drill 1/16 in. hole at each end of crack
Tank shell
(a)
Flanged reinforce-ment
Crack
Rivets
1/16" Drill at end of crack
(b)

FIG. 89.—(*a*) Repair of baffle crack; (*b*) repair of crack in lightening hole flange.

To close the inspection hole, it is necessary to roll the edge of the hole and the patch to form a flange weld, which is then welded according to the procedure of Job Unit 18.

Where the cracked baffle is repaired by riveting, a hole is drilled at the end of the crack as for welding and a patch riveted in position to straddle the crack, as is shown in Fig. 89*a*. Where reinforcement between the baffle and the tank shell is required, it becomes necessary to rivet the strap to the shell and the baffle with sufficient rivets which are spaced no closer than six rivet diameters. *When using brass or steel reinforcements instead of aluminum, their surfaces which are in contact with the aluminum must be tinned to minimize corrosion.* If steel, brass, or copper rivets are used, these must be completely tinned before using.

130. Spot Welding of Aluminum.—Resistance welding of aluminum is restricted to *spot welding.* When a high-quality spot weld is to be obtained, suitable equipment must be available. The *minimum requirements are:* A *transformer* of adequate capacity, an *electrode-pressure device,* and *precision time control* for the power impulse. Equipment which is *lacking* in any one of these details is *wholly unsatisfactory* for the spot-welding requirements. The *accuracy* with which these factors are controlled independently of the operator *determines* in a large measure the *success or the failure* of the spot weld. The most important factors are enumerated in the following outline:

1. *Heat Generated for Given Current and Resistance of Specimen Metal.*—The surfaces of the specimen must be clean to establish electrical contact. The capacity of the welder to produce large currents at a low impressed voltage is inherent in the design of the welding unit available. *Only* by manipulation of *electrode pressure, power impulse, time,* and *current taps* can optimum results be obtained.

2. *Pressure at Electrodes.*—Aluminum alloys have little or no compressive strength at fusion temperatures. Electrode contact with the surfaces must be firmly established with the proper diameter and kept cool at the electrode tip in order to localize fusion between interfaces of the metal and to prevent serious undercutting of the areas in contact with the electrodes. *When the pressure is insufficient to maintain electrical contact, arcing may occur, which either fuses the sheet to the electrodes or leaves a porous weld.*

3. *Electrode Shape.*—Relatively small electrodes insure the required high-current density with the least disturbance of the magnetic field. A cylindrically shaped lower electrode with a flat top and an upper electrode tip which is slightly spherical produce welds without undercutting when the electrode pressure is correctly adjusted. *Tips which are refinished with a file leave their rough imprint on the specimen and increase metal pickup by the electrode.* Redressing with fine sandpaper produces the best finish, unless there is serious deformation.

4. *Time Duration of Power Impulse.*—A prolonged power cycle produces a rapid deterioration in strength. A power impulse which is too short in duration, unless it is of high amperage, results in an imperfect band between metals at the electrode tips. *Accurate timing is essential for duplication of results.*

5. *Condition of Metal to Be Welded as Affected by Temperature.*—Duralumin, or 24ST, maintains a surface without undercutting when current density is high, electrode contact is cool, pressure is moderate, and time impulse is a minimum. Duralumin does not appear to age naturally after welding or to regain the strength at the weld. Subsequent heat treatment for such a small area as a spot weld involves additional handling and cost.

6. *Thickness of Metal.*—Very thin gauges cool quickly and develop higher unit strengths for the same type of joint (lap, or butt with single-corner or

double-corner plates). *Special jigs are an essential part of equipment to insure alignment of adjacent parts.* Elastic failure in misaligned parts intensifies the unit stress in the weld, which can least afford to be jeopardized. Heavy-gauge metal localizes loads in the softer weld if allowed to remain in the structure. Double or triple rows of alternately spaced welds furnish necessary stiffness at the juncture of the plates to intensify stress in multiple-spot welds. Tests show that the strength does not increase directly with the increase in number of spot welds.

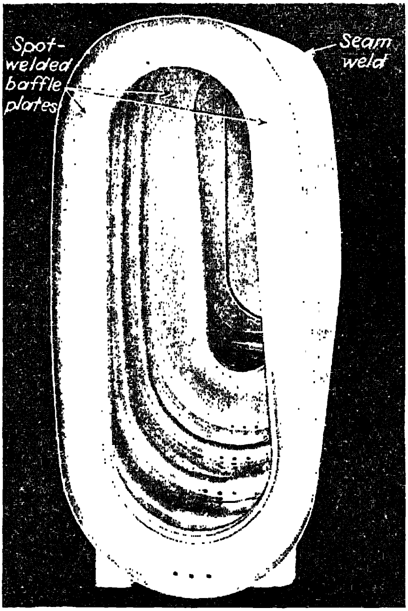

FIG. 90.—Examples of spot and seam welding. (*Courtesy, Aluminum Company of America.*)

7. *Length of Secondary Leads.*—The use of short leads reduces voltage drop to a minimum value for maximum current density at the weld.

8. *Spacing of Welds.*—Owing to the presence of adjoining spot welds, an electrical shunt exists which diverts a portion of the current from the weld being made. As much as 10 per cent additional current is required to produce an equivalent strength in welds. *According to available research, ½ in. spacing develops the best results in thin-gauge welds.*

Typical values of these quantities for spot welding aluminum are given in Table XIV.

When automatic resistance-welding equipment is used and the least welding time, electrode pressure, and welding current are accurately controlled, welds comparable with rivet strength are produced with little or no deterioration under corrosion. *A series of spot-welded joints under accurate conditions of control produce tensile strength in spot welds about the same as riveted joints* (see Table XV).

A spot-welded fuel tank in which the joining has been made exclusively by the spot-welding process is shown in Fig. 90.

Table XIV.—Approximate Values of Spot-welding Variables for Aluminum

Thickness, in.	Cycles of 60-cycle power	Amperes, approximate	Electrode pressure, lb.
0.020	1	16,000	300 to 500
0.036	2	20,000	400 to 650
0.064	4	24,000	500 to 800
0.081	6	28,000	600 to 700
0.125	9	35,000	700 to 1200

Courtesy of Aluminum Company of America.

Table XV.—Tensile Strength of Spot Welds in Alclad Aluminum 17ST Alloy*

Gauge, in.	Spots or rivets per inch	Spot-weld strength, lb.	Rivet strength, lb.
0.016	3	406	336†
0.016	2	258	224
0.016	1	147	112
0.020	3	528	420
0.020	2	356	280
0.020	1	177	420
0.032	3	880	900‡
0.032	2	690	600
0.032	1	320	300
0.051	3	1360	1077
0.051	2	914	736
0.051	1	490	368
0.064	3	1940	1079
0.064	2	1335	736
0.064	1	675	368

* These values should not be used for design as they represent the average of only four specimens.

† These six tests made with 3/32-in. rivets.

‡ These nine tests made with 1/8-in. rivets.

Courtesy of Aluminum Company of America.

131. Hard-surfacing.—An important part of airplane maintenance is the method of surfacing parts to resist wear and high temperature, such as found on tail skids (Fig. 91) and valve seats (Fig. 98). Hard-surfacing materials which are laid on to steel, or metal with poor wearing qualities, possess the following physical properties:

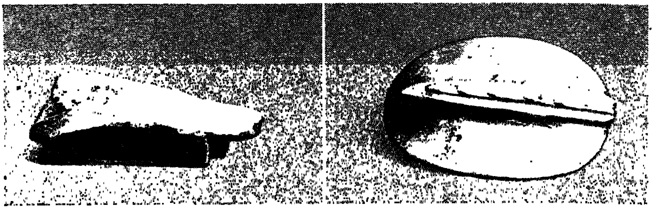

FIG. 91.—Hard-surfaced tail-skid shoe after 1,061 landings or 116,900 yards. (*Courtesy of Haynes Stellite Company.*)

1. Resistance to abrasion, wear, and corrosion.
2. Maintenance of hardness and wear resistance at red heats.
3. Low coefficient of friction.
4. Coefficient of expansion approximating that of steel.
5. Lower melting temperatures of steel, so that the steel solidifies first and absorbs some of the shrinkage of the hard-surfacing material which otherwise would crack or spawl if the shrinkage were absorbed in the hard-surfacing material.

132. Preparation of Surfaces.—These hard-surfacing materials may be applied to steel in the rod or pellet form. Before proceeding with the hard-surfacing operation, the surface to be overlaid must be cleaned of scale and surface accumulations by sandblasting, grinding, filing, or scraping. Surfaces which are to be coated should be ground to rounded edges. Square edges or corners of this hard-surfacing metal chip under impact.

The surface to be coated is preheated to a dull-red heat.

133. Hard-surfacing Method.—Select a tip size of one size larger than the corresponding size of tip which is required for the same thickness of steel. The welding flame should be adjusted so that the excess acetylene off the end of the inner zone is produced twice as long as the length of the inner zone. The usual test for the proper amount of excess acetylene is by studying the surface under the flame. An excess which is too great will appear as black carbon deposit on the surface of the weld. With insufficient excess acetylene, the hard-surfacing material will boil.

The torch should be directed in a position 30 deg. from the surface being coated so that the flame does not penetrate the molten metal and form blowholes. Before applying any hard-surfacing material, the skid shoe or valve seat should be preheated to a dull-red heat and maintained at this temperature to prevent surface cracks. The first layer of hard-surfacing material may be laid on in an operation very similar to tinning when the metal is at the proper heat. Additional layers are built up until the thickness of hard-surfacing is reached. *At the completion of hard-surfacing, the skid shoe should be covered and allowed to cool to prevent checking of the hard surface.*

The *electric arc* is used for hard-surfacing by making the coated electrode the positive terminal and the part being hard-surfaced the negative terminal. The operation produces a smoother finish and is more permanent with flux-coated electrodes, using welding currents between 200 and 250 amp., depending upon the rod size and the thickness of the plate being hard-surfaced.

134. Stainless-steel Welding. *Flame Welding.*—The steels composed largely of 18 per cent chromium and 8 per cent nickel, or briefly 18 and 8, are known as *stainless steel.* The light gauges of this metal are commonly encountered in maintenance, and satisfactory welds can be made with the gas flame and the electric arc or by resistance welding. For thicknesses less than 1/16 in. the oxyacetylene process is recommended. For greater thicknesses, the arc-welding process is faster and preserves the corrosion-resisting properties of this steel. During the welding process by either method, suitable flux is required on the top and the reverse surfaces to prevent oxidation in the welding atmospheres.

A neutral flame should always be used in gas welding to obtain maximum strength and ductility. An excess acetylene flame increases the hard carbide content of the weld metal, reducing ductility and corrosion resistance, whereas *excess of oxygen flame produces hard oxides and porous welds and therefore should be avoided.*

A small flame should be used but of sufficient size to fuse the area under the inner cone of the flame. *Only* by using a *welding rod* similar to the plate composition and containing a limited amount of columbium, molybdenum, or titanium can the precipitation of harmful carbides at the grain boundaries be prevented, particularly in the zone approaching 1400°F. at the edge of the weld and parallel to it. In *rapid welding*, this zone may be narrowed sufficiently to prevent corrosion and lessen the tendency to *warpage* in thin sheets. After the weld is finished, additional heat treatment is not absolutely necessary in exhaust-collector rings (Fig. 92). If it is desirable to preserve the finish so as to repolish the surface, the parts may be heated carefully so as to prevent warpage in the parts to a temperature in excess of 1900°F. followed by rapid cooling which occurs in thin-gauge metals in air.

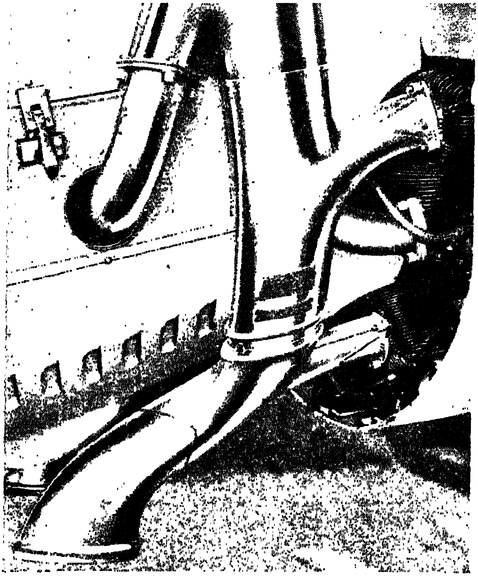

FIG. 92.—Exhaust collector ring. (*Courtesy of Republic Steel Corp.*)

135. Arc Welding.—Arc welds on stainless steel are most satisfactory when the thickness is greater than 1/16 in. The electrode used has a flux coating and is made the positive terminal in an electric-welding circuit. This is another way of saying that reversal polarity is employed to obtain satisfactory arc-weld deposits. *For repair welding on stainless steel with the electric arc,* *it is recommended that support be given the seam by clamping in a suitable jig.* This jig consists of a copper bar with a slight groove placed in line with the crack, and clamps to hold the steel in place.

TABLE XVI.—ARC WELDING OF STAINLESS STEEL*

Gauge, in.	Current, amp.	Voltage operating	Electrode diameter, in.
0.062	35– 70	35–40	3/32
0.094	40– 80	38–42	3/32
0.125	60–100	40–45	1/8
0.156	80–150	45–50	5/32
0.1875	105–165	55–60	3/16

* Arc lengths maintained as consistently short as necessary for sound weld. Fit-up of parts to be reasonably close or within 1/32 in. with clamping to insure its maintenance. Kerf for 3/16 in. or less should be planed squarely or sheared without burrs remaining.

136. Spot Welding.—Spot welding of stainless steel can be depended upon to produce welds approaching in strength, ductility, and toughness those of the original sheet. The factors most important in this type of welding are the same as outlined for aluminum. Specific values of *current, electrode size, pressure,* and *timing cycle* depend upon the class of work, the gauge, and the stainless steel which is welded. *The exact procedure must be arrived at by varying these factors until the desired result of fusion is obtained. Undercutting* or *brinelling* effect is avoided by interposing a copper or aluminum block between the sheet and the electrode so that the resulting electrode pressure is absorbed in the copper or aluminum. Copper is preferred since it has a higher melting point and does not readily pit and draw a slight arc such as does aluminum, which dissipates the welding energy at points other than between the interfaces of the sheet.

137. Silver Soldering.—This is a method of bonding metals where *structural strength is not an important factor.* This solder is compounded principally of silver, copper, and nickel. Typical joints which are silver-soldered are those in copper or Monel-metal fuel lines and stainless-steel parts. *Tempered-steel wires should not be soldered, but clamped, pinned, or bolted instead.*

Hard-soldering is done with a flux of borax by tinning the surfaces in contact to be soldered. A strictly neutral flame should be maintained to prevent oxidation and solder embrittlement. The mating parts are sweated to permit the solder to flow between the interfaces. *In repair work, soldered joints should never be welded.* All the solder should be removed by melting, scraping, or filing before welding. Obviously it is possible to solder welded parts. Prolonged heating of cold-drawn or cold-rolled stock softens or weakens the areas affected by heat. A soldering speed consistent with good bonding should be the rule.

For stainless steel, soldering is done with the low-melting-point silver solder, because there is less tendency of scale formation and serious warpage. *A special flux is required for the soldering of stainless steel.* Overheating should be avoided because surface cracks are developed in the stainless steel by the usual silver solder.

138. Brazing.—The brazing process differs from silver soldering only in the respect that the copper-tin-zinc mixture is applied between adjacent parts. The flux which must be used is largely borax or boracic acid. Copper, Monel, and steels are readily brazed, with shear strength of 10,000 lb. per square inch.

Brazing shall not be considered a structural connection in a primary structure. In order to braze it is necessary to clean the adjoining surfaces of grease, scale, and accumulations. Each of these cleaned parts is tinned by adjusting heat to fluxing surfaces. Torch, or arc, or resistance heat sources are used.

Brazing is limited to parts in compression or shear. The mating parts to be brazed are clamped in position for the operation. Brazing of stainless steel is satisfactorily done by using similar techniques, with the exception that special brazing flux that removes scale and insures continuous bond may be used. A few types of brazed joints are outlined in the accompanying sketches.

Brazed joints are designed for shear, so that any arrangement developing maximum shear resistance is preferred. The "lap joint" is generally used because it is possible to vary the lap area to incorporate any margin of safety, owing to the small area of brazing alloy exposed. Moreover, lap joints offer better resistance to corrosion. These joints are readily held by suitable fixtures with close control of tolerances. With flat parts, a light pressure by added weight in a convenient place on the part assures complete bonding. Where tubular members are brazed or silver-soldered, pressure cannot be exerted and capillarity and surface tension, which are dependent upon heat control, become controlling factors.

139. Repair of Tubular Members by Welding.—Most of the steel in the structural tubes of metal aircraft is chrome-molybdenum (S. A. E. 4130), usually in the normalized condition with a tensile strength of 95,000 lb. per square inch. Such members as the landing gear and wing cells are designed for much higher physical properties since the compressive loads are in excess of the usual requirements. Welding heats lessen these high physical properties in local areas if welding is attempted. If greater column strength is required, localized welding of the fittings near the extremities of the affected members is possible without impairing the column strength.

Any repair, which involves welding of an existing structure *should be undertaken only after a careful study by competent authorities* is made of the drawings and the loads carried by each member, to insure that proper consideration is given each item of repair. When this study discloses that no special properties are needed, damaged parts can be repaired, reinforced, or replaced.

General Principles of Welded Tubular Construction.—The structural members of an airplane, that is, the fuselage, engine mounts, wing sections, etc., are subjected to *tension*, *compression*, *bending*, and *vibration*. The size of tube, plate, or shape used is computed for one or more of these. In a typical case, if a large ratio of length to diameter is assumed, the members crush at the ends and bend in the center of the structural member, when welded. The stress rarely is equally distributed. Probably the stress is a maximum at the center section, nearly a maximum at the ends, and a minimum approximately 20 per cent of the length from both ends.

Although the stress is greatest at the center, failure occurs at the tube ends when the tube has bent permanently. The analysis explains how stiffness and strength are obtained when joining end to end by telescoping rather than by butt welding.

Structural members in a fuselage are under tension, compression, and bending loads of varying intensity. The tube size, or plate thickness, is calculated for one or several predominant stresses. In a typical instance of a tube where a large ratio of length to diameter is used, the welds at the ends can safely develop the plate strength *only when the joints receive heat treatment;* otherwise the crushing strength in the annealed section of the weld is reduced below that of the tube. This critical section requires suitable reinforcement, such as a strap or sleeve tube to stiffen the gusset with adequate reinforcement at the tube ends. *The tube should bend in the center.*

Further extension of the analysis for the weld construction explains why unnecessary application of heat near critical sections should be avoided. For instance, holes drilled for injecting lion-oil to prevent internal corrosion of structural tubes are located usually beyond the critical section of the weld which is more than two weld-bead widths from the weld in gas-welded members and one weld-bead width for arc welds. *These drill holes should be closed with a screw plug instead of by welding.* Consequently a tube under compression should not be heated in any portion between the ends.

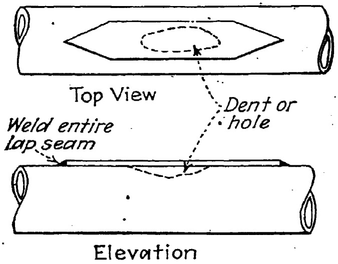

FIG. 93.—Repair of dent with patch.

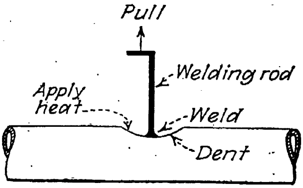

FIG. 94.—Repair of slight tube dent.

The practice of placing solid gussets between tubes intersecting at an angle less than 30 deg. imposes crushing tensile and shear stresses at the welded joint and collapses the tube by buckling in the first 20 per cent of the tube length. Either strap gussets or no gussets are used.

A weld deposit with concave bead is to be preferred where vibration is an important consideration. Chrome-molybdenum steel is of less advantage in locations where there is vibration as, for example, in engine mounts.

The usual occurrence of failure outside the weld in a well-executed joint shows that the strength is not dependent upon the weld so much as upon the extent to which members welded are weakened by the welding process.

140. Reconditioning of Minor Dents.—Dents in tubes not heat-treated are often removed as shown in Figs. 93 and 94.

Local dents in heat-treated compression tubes are often repaired by using a splint tube or splint over the damaged tube in a manner shown in Fig. 95. The splint tube must be of the same material and thickness as the dented tube, and be clamped tightly so that neither the clamps nor splint will loosen in service. The spacing of these clamps and essential dimensions of the splint tube, so that its inside diameter will fit by telescoping the damaged tube, appear in Fig. 95.

For repair of larger dents in tubes which are not heat-treated, a patch of the shape in Fig. 93 and thickness of the damaged tube is welded in place. Preference is given the tapered patch to reduce excessive length of welding bead with consequent loss of tube strength.

141. Strengthening of Compression Members.—Reinforcement of compression members in the fuselage may be done with a splint and clamps welded to one half of the splint. The splint should be of the same type of steel and the same gauge thickness as the original tubing. Additional stiffening of the repair section is obtained with strap gussets (Fig. 95). When the member is in compression, a flat-ended splint is used. For a member under tension and compression each half of the ends of the splint tube is cut at an angle less than 30 deg.

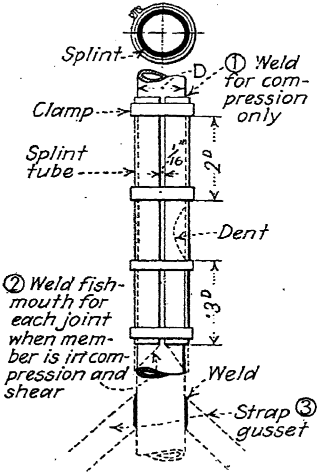
Splint
D
① Weld for compression only
Clamp
Splint tube
$\frac{1}{16}$"
2D
Dent
② Weld fishmouth for each joint when member is in compression and shear
3D
Weld
Strap ③ gusset

FIG. 95.—Repair of compression member. Items 1, 2, 3 refer to repair of fuselage member.

Damaged fittings should be replaced by cutting each tube in the cluster joint of which the fitting is a part *at a distance no less than four times the tube diameter.* The replacement fitting with a corresponding stub tube welded in position is positioned in alignment with its mating tubes over which have previously been slipped the sleeves of the same material and wall thickness as the original tube. These sleeves are cut to form a fishmouth which is welded in the position shown in Fig. 96*c*.

142. Longeron Repairs.—Split or broken tubes must be removed and a suitable replacement must be inserted in their stead. Several alternative splices may be used. *But only the welded joints providing the maximum strength under tensile and bending loads, or splices which develop the original tube strength, are recommended.*

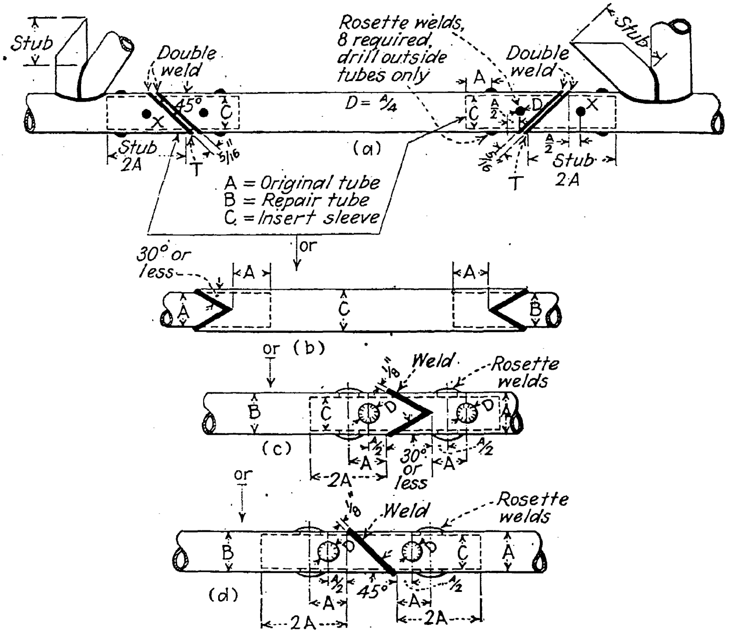

FIG. 96.—Alternate methods of tube repair.

The method of making this repair is outlined in the following paragraphs:

The *damaged tube is removed* so that the stub end remaining in the cluster is at least four times the tube diameter. The slope of the fishmouth sections should be 30 deg. or less (Fig. 96), while the end of the scarf tube should be 45 deg. or less (Fig. 96*a*).

For the *fishmouth-tube weld*, the splice tube or sleeve is recommended in all joints because of its greater strength in bending. However, an insert tube welded in a scarf joint in the manner of Fig. 96*c* shows equally as great a resistance in bending.

The *final repair section* differs only in type of weld, either fishmouth or scarf, and the two kinds of sleeves in the splice, outside or inside. Figures 96*b* and *d* show these in position for each particular type of repair.

An *inside sleeve* is cut to a length four and one half times the diameter of the damaged tube, and the stub tube at the cluster joint is shaped to a V, as shown, with two ¼-in. holes drilled at 90 deg. in the outer tube only.

To *assemble the joint,* start at *T*. Insert the inside sleeve of the same gauge and material as in the original tube until the end is flush with *X*. Do the same at the opposite cluster. Center the repair tube and fish through the outside holes with a scriber, and move the inside sleeve in the position shown in Fig. 96*a*. When thus located, seal all holes in the outside tubes, or four on either end of the repair section, by rosette welds. Tack-weld each scarf joint at equidistant points. Then weld away from points by backward welding to prevent burning through the tube.

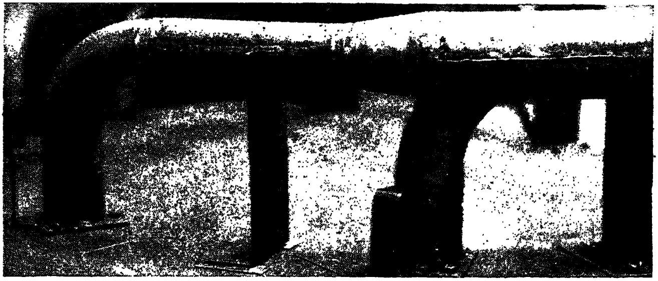

Fig. 97.—Exhaust-stack jig. (*Courtesy of Linde Air Products Company.*)

In Fig. 96*b* are shown the details of a very satisfactory repair which differs from the previous repair in that the outside sleeve with the same gauge and material as the original tube is used, and no rosette welds are made.

A *fishmouth splice* requiring a single weld and using an insert sleeve and outside tubes cut at 30 deg. is shown in Fig. 96*c*. This repair shows a very high bending and tensile strength, equaling the original tube properties.

143. Welding Jigs.—A jig is a rigid structure which holds several parts in accurate alignment while welding is being done. *Jigs are used to locate the component parts without the necessity of* *fitting these parts in place on the airplane.* The jig is made rigid to prevent distortion of the parts which are welded. The jig is built with sufficient strength so that warping does not take place in its own structure. Assurance that the welded repair sections will fit accurately is sufficient justification for the additional expense. The time saved in positioning the adjacent parts accurately pays for the jig if it is simple in construction.

The jig for holding the parts of an exhaust stack (Fig. 97) consists of angle plates which are bolted to a bedplate. A sufficient number of these supports are used to locate the stack in the position for welding. The top of each angle plate need only be given a V-notch, which has important uses for aligning tubular members.

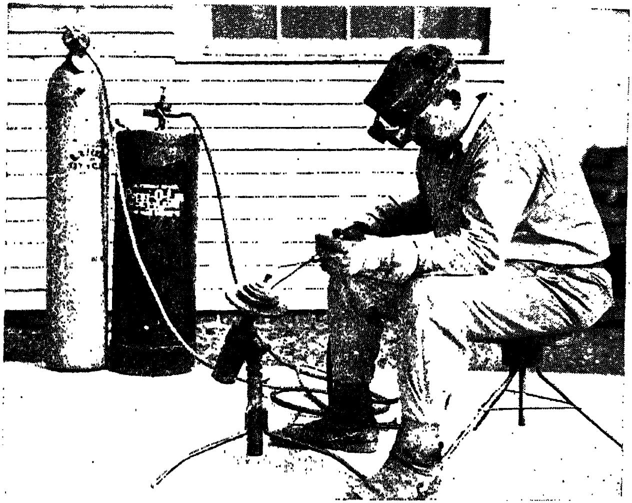

FIG. 98.—Rotary jig for hard-surfacing valve inserts. (*Courtesy of Haynes Stellite Company.*)

Another type of jig is one which rotates the work, during welding, under the torch. Such a jig is shown in Fig. 98 for hard-surfacing valve insets on valve-seat rings of aircraft engines.

The minimum requirements of welding jigs are:

1. Means provided for rapid clamping in position, for welding and detaching after welding when parts are too light for effective use of gravity.

2. Provision for necessary clearance between weld and jig to prevent arc blow and too much heat loss from weld to tube or sheet.
3. Provision for necessary convenience to permit welding in down-hand position.
4. Ability to determine size, shape, and form of ends in all segments of parts.
5. Provision for location points which permit insertion of parts only in the correct position.
6. Economy without sacrifice of accuracy.
7. Freedom from sharp edges and corners, which injure operators.
8. Positions of all locating points, their mechanical movements, and the effect of welding heats on them taken into account.
9. Provision for removal of the completed part without loss of time; C-clamps and holding clips which may be slipped in place and removed, reduce the jig cost.

WELDING JOB UNITS

The following welding jobs have been arranged progressively from the simple welding exercises to complex joints. The experienced welder should be able to execute any job creditably. But the apprentice welder should proceed from the simplest job and gradually perfect his technique until he is capable of welding the most complicated joint with ease.

The welding instructor is advised to grade the apprentice on such details as care of equipment, facility with torch and equipment, workmanship, and knowledge of correct welding procedure.

In each job unit questions are listed under the discussion to stimulate thought and develop a critical analysis of the particular details of welding.

GENERAL INSTRUCTIONS FOR OXYACTELYENE JOB UNITS

Purpose: To familiarize the student with the method and technique of welding steel.

Equipment

1. Oxygen and acetylene regulators.
2. Aircraft torch or blowpipe.
3. Torch tips for metal thicknesses to be welded (Table XI).
4. Accessories—wrenches, spark lighter, gloves, goggles, wire brush.

Materials

1. Welding rod of suitable chemical analysis.
2. Cold-rolled plate stock or drawn tubing of either S. A. E. 1025 or S. A. E. 4130 steel.

Procedure

1. Connect the equipment above as described in Par. 123.
2. With emery cloth, file, or wire brush clean the surfaces to be welded.
3. Shear or cut all flat stock or tubes and place these with mating distance of $\frac{1}{32}$ in. between the plate and tube edges.
4. Instructor outlines method of welding the plate or tube or both. Specimen weld for particular job unit, which has been done by instructor, is studied.
5. Student makes up the joint of the two or more parts and places tack welds according to directions in the job unit.
6. Student completes the weld.
7. Inspection of finished weld in manner described below furnishes the means of analyzing the results and correction of errors in welding technique.
8. The completed weld is submitted to instructor, who discusses the results and means of improvement with each welder.

Inspection

1. Visual examination is done to detect surface defects, such as blowholes and cracks, bead proportions, and workmanship.
2. The penetration is determined by sectioning crosswise of weld with a hacksaw and polishing with emery cloth as directed in Par. 115. On the smooth surface, 5 per cent alcoholic solution of nitric acid is placed for 5 sec. and then thoroughly rinsed off. The fused area should be at least three times the area of the original gap between the plates.
3. A section of welded plate or tube can be tested for strength and ductility in a tensile testing machine or in the case of the plate bent in a vise.

Job Unit 6. Manipulation of Welding Torch

Object: To handle the welding torch when laying a bead in thin steel plate.

Equipment: Same as general instructions above.

Materials: Two pieces of 16-gauge sheet bent at the edges, as shown in Fig. 99.

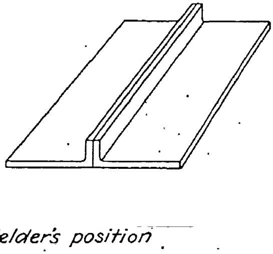

FIG. 99.—Flange weld without filler rod.

Procedure

1. Place bent edges within $\frac{1}{32}$ in. of each other.
2. Fuse the flaring edges in the flat position (Fig. 99) with the welding-torch flame. Filler rod is not to be used in this job unit.
3. Backward or forward welding may be used in welding.

Inspection

1. Determine any distortion of the weld by laying the two flat plates on a flat cast-iron or steel block before and after welding.

2. Examine weld deposit for scale, uniformity in height of bead, and roughness.

Discussion

1. How is warpage developed in this job unit?
2. How would you lessen this warpage?
3. How can irregularity in bead height be prevented?
4. Explain the means of correcting the lack of penetration to the underside of the seam.

Job Unit 7. Handling of Filler Rod

Object: To become familiar with the filler rod and with the welding torch during the welding of thin-gauge steel.

Equipment: Same as in general instructions.

Materials: 16-gauge sheet steel, 4 in. wide and 6 in. long. Filler rod of $\frac{1}{16}$ in. diameter.

Procedure

1. Slit the plate with a milling cutter or with a hacksaw blade so that four slots $\frac{1}{16}$ in. wide and 5 in. long are cut (see Fig. 100).

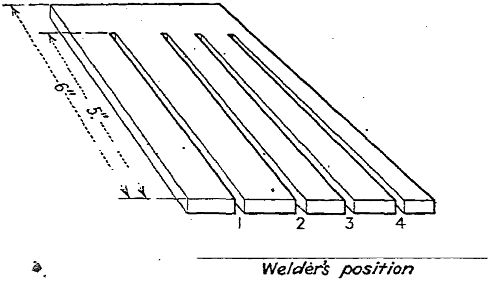

FIG. 100.—Exercise for welding with filier rod.

2. Support the plate so that no obstruction lies directly under the seam.
3. Fill each slot in succession with molten filler rod. Start the weld deposit at 1 (Fig. 100) and complete this seam by forward welding.
4. Repeat the welding of seam 2 by backward welding after commencing the deposit at the open end.
5. Weld slot 3, starting at closed end, by the backward welding method.
6. Repeat weld in slot 4 by forward welding from the closed end of the seam. In performing this job turn the plate 180 deg. from position of Fig. 100 before starting the weld.

Inspection

1. Examine each weld for surface cracks, blowholes, uniformity of bead, and workmanship.

2. Check plate for flatness by placing the sheet on a flat iron surface with grooves under each seam before and after welding.

3. Determine the penetration by sectioning the sheet with a hacksaw, and polish and etch this section according to Par. 115.

Discussion

1. How do you account for surface cracks in welds 1 and 2, and no surface cracks in welds 3 and 4?

2. Which of the two following methods of welding is apt to cause severe warpage:

a. To proceed with the weld from the open end of the seam?

b. To weld from the closed end of the slot toward the open end?

3. In welding, the general facts are that the shrinkage stresses which cause buckling of plates or tubes are held at a minimum by allowing the welded member to expand and contract freely until the weld has been complete.

Job Unit 8. Alignment

PART A. WELDING TO PRODUCE ALIGNMENT

Object: To study the preparation of seams and the use of welding equipment to maintain the alignment of parts.

Equipment: Consult general instructions.

Materials: Two pieces of 16-gauge sheet steel, 1 by 5 in. $\frac{1}{16}$-in. filler rod.

Procedure

1. Shear or trim each piece so that each end is 1 in. (Fig. 101.)

2. Set the two pieces with the initial gap at $\frac{1}{16}$ in. and the gap (I) in the opposite end at $\frac{5}{64}$ in.

3. Tack-weld at I and forward-weld the seam completing the weld at I by melting through the tack weld.

4. Grind ends to be flush with the ends of the plate.

Inspection

1. Check sides and ends with a square to determine variation from 90 deg.

2. Examine bead for blowholes, cracks, scale, and workmanship.

3. Grind, polish, and etch a cross section of the weld to determine penetration and fusion.

4. Check for warpage of the plate by laying the welded job on a flat iron block with a groove under the welded seam.

Discussion

1. Explain any distortion of the welded plates.

2. Why do you account for no buckling in this job unit?

PART B. DEVELOPMENT OF MISALIGNMENT

Object: To study the development of misalignment in adjoining parts.

Equipment and Materials: Same as Part *A*.

Procedure: Items 1 and 2 are the same as for Part *A*.

3. Do not tack-weld at any point but start the weld at the point nearer to the welder (Fig. 101) and weld the seam by forward welding.

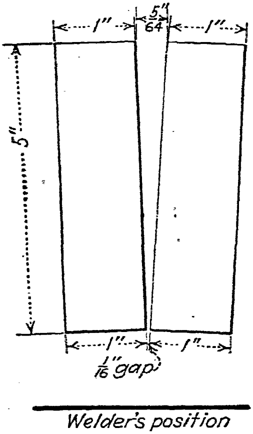

FIG. 101.—Weld with shrinkage allowance in seam.

Inspection

1. Check the end and sides for right angles with a square.
2. Examine weld for scale, blowholes, and workmanship.
3. Section, polish, and etch the weld for penetration and fusion.

Discussion: How do you explain any misalignment in Part *B* with Part *A*?

Job Unit 9. Corner Welding—Part A

Object: To use welding torch and filler rods in corner weldings while in the horizontal position.

Equipment: Consult general instructions.

Materials: Two 16-gauge sheet-steel plates 3 by 4 in.

Procedure

1. Hold the two plates on the welding table to form a tee (Fig. 102).
2. Tack-weld at three equally spaced positions, so that plates are separated by a 1/16-in. space.
3. Begin seam weld at end near welder and forward-weld the seam, melting through the tack welds.

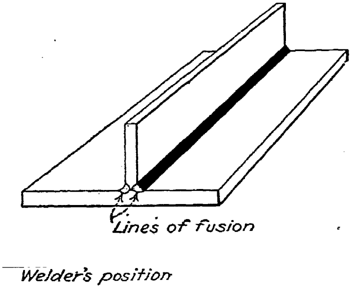

FIG. 102.—Corner weld specimen.

Inspection

1. Examine welded plates for distortion due to welding heats.
2. Examine welded areas for scale, blowholes, surface cracks, workmanship.

Discussion

1. What would happen if the seam were welded while the edges are in contact throughout their length?
2. How do you account for any distortion in the plates welded by you? What remedies can you suggest?

Job Unit 9. Corner Welding—Part B

Repeat Part *A* with tee plate joint by welding in the vertical position.

Job Unit 9. Corner Welding with Plates of Different Thicknesses—Part C

Object: Same as Part *A* with the exception that the plates are of different thickness, and the angle is 45 deg.

Equipment: See general instructions.

Materials: One piece sheet steel 16 gauge, $\frac{1}{8}$ by $\frac{3}{4}$ by 4 in.; one piece $\frac{3}{16}$-in. flat-stock steel, $\frac{3}{16}$ by $\frac{3}{4}$ by 4 in.

Method

1. Lay the $\frac{1}{8}$ by $\frac{3}{4}$ by 4-in. piece on the welding table and stand a 16 gauge piece in place so it inclines 45 deg. with the horizontal plate [Fig. 103(1)].

2. Tack-weld ends at three equally spaced points so plate edge and bottom plate are separated $\frac{1}{16}$ in.

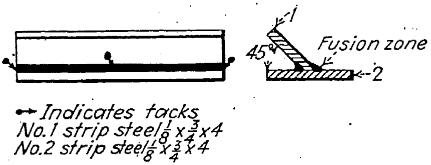
1
45°
Fusion zone
2
⟶ Indicates tacks
No.1 strip steel $\frac{1}{8}$ x $\frac{3}{4}$ x 4
No.2 strip steel $\frac{1}{8}$ x $\frac{3}{4}$ x 4

FIG. 103.—Angle plate weld.

3. Start seam weld at point opposite the welder (Fig. 103) and weld seam by backward welding on 45-deg. side. Direct the inner point of the flame at the line of intersection of the two plates.

4. Start seam weld on other side of the vertical strip at point nearest the welder, and complete seam by forward welding, directing the inner flame zone at the intersection of the two plates.

Inspection: Same as for Part *A*.

Discussion

1. Explain any distortion in the vertical plate.

2. Explain the cause of piling up metal on heavy plate and leaving the vertical plate without a head or with holes burned through it.

3. What are the advantages of tack welds in this exercise?

NOTE: Backing the vertical plate with a $\frac{3}{16}$-in. iron plate on the side opposite the weld draws heat from the plate fast enough to prevent serious warping or burning in the vertical plate.

In general, the inner zone of the flame must be directed slightly on the side of the heavier plate while welding the seam.

Job Unit 10. Rosette Weld and Washer Weld

Object: To learn how to make a rosette weld and washer weld.

Equipment: See general instructions.

Material: 16-gauge sheet 1 by 2 in., washer 12 in. in diameter.

Procedure

1. Drill $\frac{1}{4}$-in. hole in sheet. Center washer on plate as indicated in Fig. 104.

2. Fill holes with filler-rod metal by first welding around the rim of the hole and gradually reducing hole size by the width of filler-rod bead. Repeat until hole is finally welded shut.

3. Tack-weld washer in three equally spaced positions. Weld complete bead around rim of washer, approximating the bead shown in Fig. 104.

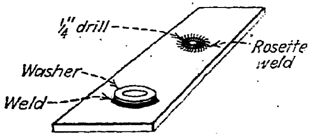

FIG. 104.—Rosette and washer weld.

Discussion

1. Explain the cause of any distortion in the plate.
2. Why are tack welds used in this job unit?

Job Unit 11. Tube Welding—Butt Joint

Object: To manipulate the torch and rod for butt weld.

Equipment and Material.—See general instructions.

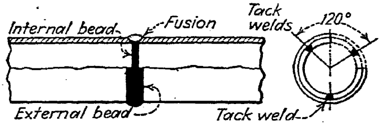

FIG. 105.—Butt weld in quarter section showing tack welds.

Procedure

1. Tack-weld as in Fig. 105.
2. Complete weld by backward welding while rotating tube under the torch.

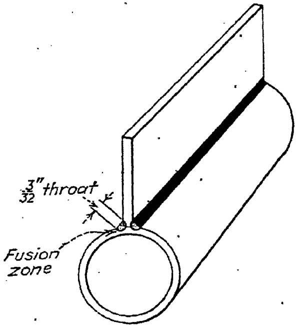

FIG. 106.—Plate-to-tube weld.

Discussion

1. Sketch a cross section of the weld showing the filler rod cross-hatched to distinguish it from the parent metal (tubing).
2. Answer the following:
   a. How is expansion compensated for in making a butt weld?
   b. Sketch a butt weld, showing effects of failure to compensate for contraction.

Job Unit 12. Plate to Tube Weld

Object: To use the method of welding a plate such as a gusset to a tube (Fig. 106).

Equipment: See general instructions.

Materials: Chrome-molybdenum-steel tubing 1 in. in diameter by 2 in. long; 16-gauge sheet 1 by 2 in.

Procedure

1. Tack-weld plate to tube, leaving a $\frac{1}{16}$-in. space between tube and plate at three equally spaced positions.
2. Start welding at point nearest to welder and forward-weld, directing the torch at the line of intersection between the plate and tube.
3. Complete the weld on the opposite side in the same manner by the backward-welding method.

Discussion

1. Examine the cross section of the welds at the juncture of the plate and tube for penetration and fusion.
2. Explain any distortion of the plate.

Job Unit 13. Cluster-joint Welding for Tubes—Part A

Object: To become familiar with the method and technique of making a cluster weld (see Fig. 108).

Equipment: Same as in general instructions.

Material: $\frac{7}{8}$-in. chrome-molybdenum steel; 3-in. stub lengths.

Procedure

1 Tack-weld tube 2 (Fig. 108) to tube 1 at three equally spaced points, so that the tubes are at right angles.

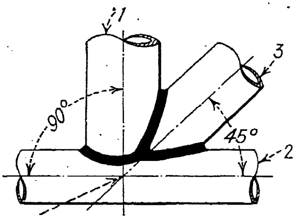

FIG. 107.—Cluster weld—two-tube section.

2. Complete the weld in the regular manner by forward or backward welding.

3. Grind tube 3 to point so as to fit space intervening between tubes 1 and 2. Tack-weld at 4 equally spaced points so that the center line of tube 3 intersects the axis of tube 1 at the same point as tube 2 in Fig. 107.

4. Complete the weld of tube 3.

5. Adjust the shrinkage stresses in the following manner: Heat the entire welded area to a dull-red heat. Immediately transfer the heat to tube 1 on the side opposite of weld and raise the temperature to dull-red heat over an area approximating three times the cross section of the two tubes.

Job Unit 14. Seven-tube Cluster Weld—Part B

All details the same as Part *A* except the sequence of tube assembly (Fig. 108).

Procedure

1. Tube 2 is tacked and completely welded to form T-joint at right angles to tube 1. Similarly, tube 3 at 90 deg. is welded into a T-joint, by tacking and fusing in place.

2. Tubes 4 and 5 are ground to a fishtail, saddling at the junction of tubes 1 and 2. In succession tube 4 is tacked and welded, then tube 5. The center lines of tubes 4 and 5 intersect in the manner of Fig. 108. The procedure in welding fishtail joints is to proceed, after tacking in three equidistant points, from the wedge-point intersection of the angle tubes such as 4, 5, 6, 7, by backward-welding until one-fourth of the weld length is finished, then speed up the operation to prevent burning through. The important fact to remember is that the heat at the apex of the angle is dissipated most rapidly; it is necessary, therefore, to direct the heat toward the solid tube to obtain uniform fusion. Maintain a weld bead of concave contour.

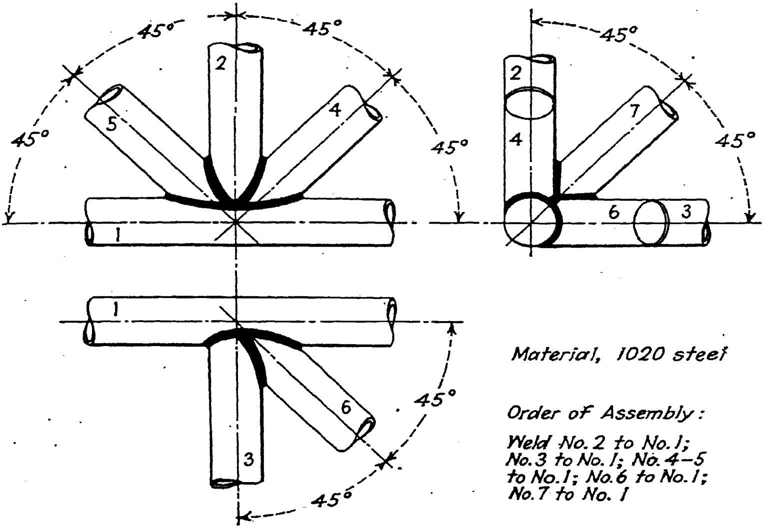

Fig. 108.—Cluster weld.

3. Tube 6 is ground to a fishtail and saddled between 1 and 3 where it is tacked and welded to these tubes.

4. Finally tube 7 is tack-welded at the juncture of 1, 2, and 3, then completely welded at their intersection.

Fig. 109.—Finished cluster weld.

5. Adjust the shrinkage stresses by heating the entire welded area to a dull-red heat followed by heating tube 1 to dull-red heat on the surface to

the width of the weld between tubes 4 and 5 and around the circumference from weld to weld. Allow the weld to cool to room temperature. This heating and cooling maintains the alignment of the tubes in the cluster.

6. The finished joint appears in Fig. 109. Note concave contour of welds and all tube intersections. Undercutting or excessive reinforcement of the bead will cause the rejection of the welded cluster.

Job Unit 15. Repair Weld

Object: To become familiar with method of making a repair weld.

Equipment: Consult general instructions.

Material: Obtain insert tube which fits freely enough to slide in a ¾-in. repair tube with a repair joint.

Procedure

1. Consult Par. 142 for nature and parts of a repair joint.
2. Prepare parts from instructions given in Par. 142.

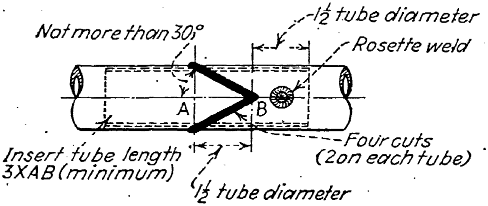

FIG. 110.—Fishmouth repair weld.

3. Assemble parts as directed in Par. 142, only for one joint instead of two, as shown in Fig. 110.
4. Lay parts as assembled flat on the welding table and close four holes on one end of joint with rosette welds.
5. Tack-weld repair joint of item 4 at four equidistant points.
6. Weld seam halfway around the tube, then turn parts formerly on underside to upper side, and complete the welding of the seam. Melt all tack welds as the welding proceeds through them.

Inspection: As outlined in general instructions.

Discussion

1. Explain any distortion or warpage in the joint.
2. When is the repair joint used in airplane welding?
3. How is alignment maintained while welding a repair joint?
4. In what manner are expansion and contraction provided for in this repair joint?

Job Unit 16. Brazed Joint—Part A

Object: To fasten washer to plate by brazing. This type of joint is common practice in fastening spacing washers to the engine mount ring.

Equipment: Gas-welding supplies.

Materials: Tobin bronze filler rod, brazing flux. Steel washers ½ in., 16-gauge plate ¾ by 4½ in.

Procedure

1. In position to be taken by washer (Fig. 111*a*) raise the temperature to dull-red heat, apply brazing flux and apply bronze rod sufficiently to tin the surface.
2. Heat the washer to dull-red heat and place in the tinned area.
3. Maintaining the dull-red heat of the steel parts, lay a bead of the bronze rod around the circumference of the washer, producing a concave contour to this bead (Fig. 111*a*).

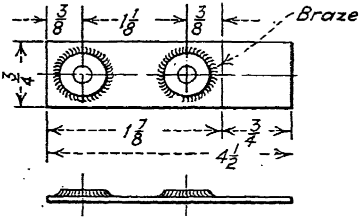

Fig. 111*a*.—Brazed washer on steel.

Job Unit 17. Sleeve Joint—Part B

Object: To braze the insert tube and the mating tube. This joint is often used in terminal fittings or in terminal struts.

Equipment: Same as Part *A*.

Materials: One inch chrome-molybdenum with 0.058-in. wall thickness and 3 in. long, ⅞-in. chrome-molybdenum-steel tubing with 0.058-in. wall thickness, 3 in. long.

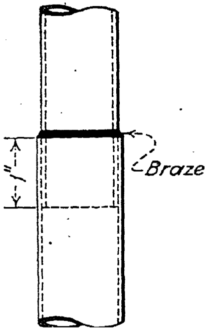

Fig. 111*b*.—Brazed insert tube.

Procedure

1. Insert ⅞-in. tubing to depth of 1 in. (Fig. 111*b*). Fasten combined tubes in the vertical position. Heat the overlapping section of these two tubes to red heat.
2. Apply brazing flux until the exposed end of the sleeve is wetted.
3. Maintaining the same temperature with neutral oxyacetylene flame, fuse bronze rod so as to completely fill the intervening space between the tubes (Fig. 111*b*) and finish off concave bead at the projecting surface of the 1-in. tube.

Job Unit 18. Aluminum-sheet Welds—Part A

Object: To become familiar with welding aluminum sheet with an oxyhydrogen flame.

Equipment: Hydrogen tank, tank of oxygen, regulators, oxyhydrogen torch, suitable tips for work in the experiment (see Table XII), hose, goggles, and spark lighter.

Material: 16-gauge sheet aluminum, aluminum flux.

Procedure

1. Apply flux on cleaned surface of plate (see Par. 100).
2. Use aluminum sheets in the position of Fig. 112.
3. Wash off flux as directed in Par. 128.
4. Flange two pieces, 2 in. wide and 4 in. long, from 16-gauge aluminum, as illustrated in Fig. 112.

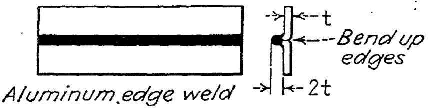

FIG. 112.—Aluminum-plate weld.

5. Lay the edges with a $\frac{1}{32}$-in. gap between the two plates. Support the plates on both sides of the seam from underneath with ground iron plate, at least $\frac{1}{2}$ in. thick, 1 in. wide, and 7 in. long.

Inspection

1. Examine weld for surface cracks, cold shuts, appearance of head, and workmanship.
2. Bend one weld lengthwise of the seam to test for fusion and strength of weld.

Discussion

1. Explain any distortion of the plate.
2. How would you prepare the seams in the sheet aluminum to reduce cracking of the weld and warpage? See Par. 122.

Job Unit 19. Aluminum-sheet Weld—Part B

Procedure

1. Drill $1\frac{1}{2}$-in. hole and roll edge as shown in Fig. 113.
2. Flange $1\frac{3}{4}$-in. aluminum disk to fit hole (Fig. 113).

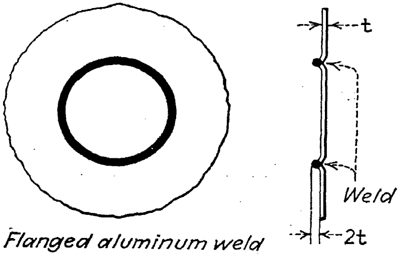

FIG. 113.—Aluminum-sheet weld.

3. Tack-weld disk at three equally spaced points.
4. Support on iron plate.

5. Clean surfaces to be fused and coat with flux, as directed in Par. 100.
6. Weld seam with rod by forward welding (Fig. 113).
7. Cleanse flux from weld as directed in Par. 128.

Inspection.—Same as for Part *A*.

Discussion

1. How are the expansion and contraction provided for in this joint?
2. Where will this type of joint be found in airplane construction?

Job Unit 20. Fishplate Welding

Object: To weld an insert plate in a slotted tube. These insert plates are used for wing hinges and engine-mount fastenings.

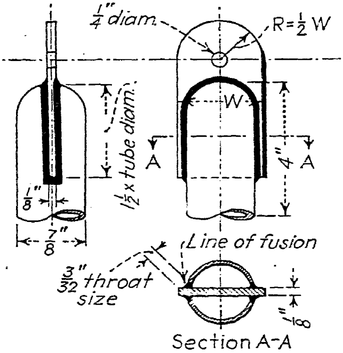

FIG. 114.—Fishplate weld details.

Equipment: See general instructions.

Materials: S. A. E. 1020 steel plate of ⅛ in. thickness and cut to the shape of Fig. 114. Mild-steel tube ⅞ in. in diameter, 4 in. long.

Procedure

1. Slot tube with ⅛-in. milling cutter to a depth of one and one-half times the tube diameter.
2. Insert plate to full depth of slot and upset slotted end of the tube to rounded surface (Fig. 114).
3. Tack-weld both sides of the fishplate to the tube at points indicated in Fig. 114.
4. By backward welding from point end of tube, completely weld one-half of the seam, directing the welding flame against the heavy plate in such a way that the tube is not burned through. All welds should have a concave contour.
5. Turn the tube and plate over and weld the opposite half in a similar manner.
6. Turn the tube to the reverse side and complete the remaining half of the plate and tube-weld by starting at the tip of the tube.
7. Again turn the tube over and weld from the point of the tube and finish the tube with backward welding.
8. Complete the weld at the edge of the plate and the tube with concave bead.

Discussion.—Outline the steps required to maintain the fishplate in alignment with axis of the tube.

Job Unit 21. Motor-mount Ring

Object: To fabricate motor-mount ring and fittings for Wright J-5 radial engine. This ring is for Boeing 203 engine mount with integral rubber shock absorbers similar to Fig. 115*c*.

Equipment: Oxyacetylene-welding supplies, tube-bending fixture.

Materials

1. S. A. E. 1020 steel tubing, 1¼ in. in diameter, 0.065-in. wall thickness, and 66 in. long;
2. S. A. E. 1020, ½-in. steel tubing, 0.065-in. wall thickness, and 10½ in. long.
3. Ten pieces of S. A. E. 1020 steel flat 16-gauge thickness, as shown in Fig. 115*a*.
4. 8 U-straps of 16-gauge S. A. E. 1020 steel, which are bent in the manner of Fig. 115*b*.

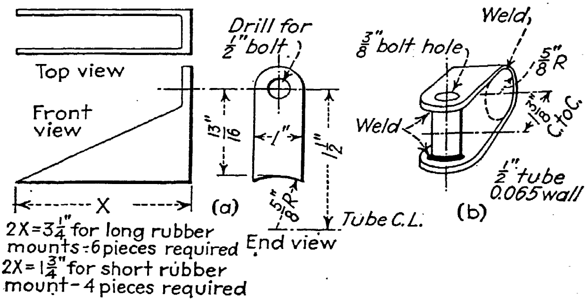

FIG. 115 *a* and *b*.—U-strap fitting. Details for motor-mount ring, eight required.

Procedure

1. After heating the 1-in. tube to dull-red heat, bend to perfect circle with 21 in. diameter at the center line.
2. Weld ½-in. tube to U-strap which has been bent around 1¼-in. tube to form the clip fitting of Fig. 115*b*. There are eight of these to be finished before proceeding to the next operation.
3. Slip eight clip fittings through the opening of the mount ring. Complete butt weld in the usual manner by tack-welding in three equidistant points and closing the remainder of the butt joint.
4. Tack-weld clip fittings at eight equally spaced points on the mount ring (Fig. 115*c*). Weld each side of these clip fittings to mount ring for one-half the tube circle (Fig. 115*b*).
5. Make the 10 scab fittings as in Fig. 115*a*. Tack these in positions shown in Fig. 115*c* and spaced for the rubber mounting. Completely weld each pair of these scab fittings before proceeding to the next pair until each pair of the five have been welded in place (Fig. 115*a*).

METALLIC-ARC-WELDING JOB UNITS

The job units which have been outlined for oxyacetylene and oxyhydrogen welding are welded with the metallic arc as the source of heat. Consult Table XII for welding current corresponding to the gauge of steel to be welded.

When the job unit involves the welding of aluminum with the electric arc, the general principles in Par. 125 should be used as a guide.

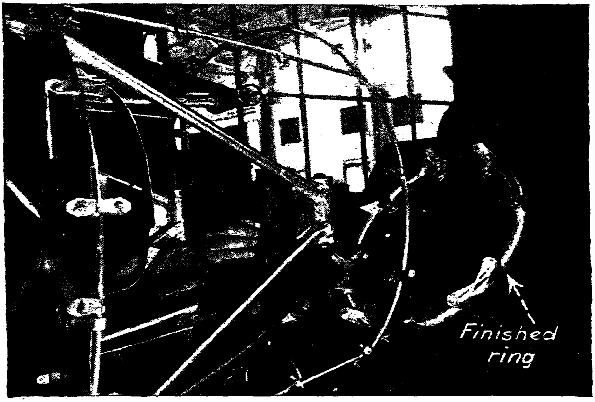

FIG. 115c.—Assembled engine-mount ring. (*Courtesy of Boeing School of Aeronautics.*)

Review Questions

1. What happens when the tip size is smaller than specified for a given thickness of tubing?

2. What condition is indicated when the molten puddle bubbles or boils? How would you stop this boiling?

3. Explain briefly the steps taken for successful butt welding of a tube to a flat plate.

4. In what way does grain size in the weld differ from that in the base metal when the proper heat is used? Why?

5. (*a*) Give the procedure for adjusting temperature stresses in a weld at a T-joint of a tube weld. (*b*) Where is the oil hole drilled? Why?

6. Name two methods of adjusting thermal stresses in arc-welded tubing.

7. Name several causes of failure in gas-welded tubing. For one of these causes of failure state the method to be used in correcting the difficulty.

8. State the reasons for the use of an excess amount of acetylene in hard-surfacing technique.

9. What are the characteristics of aluminum under welding heats?

10. Outline the method of successfully welding aluminum with the gas flame.

11. Why is a flux used in welding aluminum? Why must the remains of this flux be thoroughly removed after welding?

12. Describe the factors that influence the success in the spot welding of aluminum?

13. Is it possible in commercial aircraft to make repairs in damaged aluminum by the spot-welding method? For what reasons?

14. What are the advantages of spot-welded stainless steel?

15. Enumerate the causes of failure in arc-welded steel. State how one of these failures can be prevented by welding technique.

16. By examination of the bead that has been deposited by the electric arc, how is it possible to determine whether a long, short, or medium arc has been used?

17. What are the indications in an arc-weld deposit of excessive welding current?

18. Outline the procedure in gas-welding an aluminum tank. How are expansion and contraction adjusted in tank seams?

19. Show in cross section an appropriate sketch of the penetration, line of fusion, and bead reinforcement of the weld deposit.

20. Indicate the requirements of a sound brazed joint. Outline the technique for preparations of materials to be brazed.

21. What purposes in welded structures do jigs serve?

22. Name the different kinds of jigs that are used in alignment of aircraft parts.

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CHAPTER IX

BASIC PRINCIPLES OF THIN-SHEET-METAL STRUCTURES

A study of "Handbooks for Maintenance" of all metal transport airplanes, which are compiled by the manufacturer for maintenance stations of the commercial airline operators, shows that large proportions of the handbooks are devoted to detailed *descriptions of the structures* and to instructions for the *repair and upkeep of the structure.* In handbooks for the larger airplanes, many pages of tables are included, setting forth the *material* of every structural part and the *strength characteristic* of each item of material used. What does this mean to the airplane mechanic? It means that in the repair stations of these airlines *the shop personnel is expected to maintain the structural strength of the airplanes.*

144. Maintaining the Structural Strength.—*Maintaining the structural strength of an airplane is the most important phase of maintenance.* In this respect, the airplane mechanic's job is different from the jobs of other mechanics. For example, sheet-metal-working experience, as manufacturers and shop foremen will tell you, in most cases, is a handicap in aeronautical structural work rather than an asset. This is true because it has accustomed the mechanic to *form* sheet metal, *scribe* the surfaces of sheet metals, *punch* holes for rivets, and *head rivets* without a thought for its *structural strength.* The sheet-metal worker generally has to "unlearn" his trade and start all over again in the airplane mechanic's trade.

Before a mechanic can make repairs on an airplane structure intelligently, it is necessary that he understand the function of the various parts of the structure. This is especially true if a major repair is to be made.

It is even more important that the supervisor understands the basic principles of the structure. In the type of structure composed of wires, struts, tubes, beams, and fabric, it is immediately obvious how the basic stresses—that is, *tension, compression,* *torsion* or *shear,* and *bending*—are carried. For example, the wires obviously carry tension; the struts are designed for compression; the tubes for torsion; and the beams and spars for bending.

These facts are not so obvious in the modern, *all-metal* type of structures; and *sometimes it is difficult to understand the functions of some of the structural parts.*

145. Purpose of the Study.—This chapter is presented for the following purposes:

1. *To explain the fundamental principles* (which are very simple in nature) involved in thin-sheet-metal structures. The student can appreciate the term, "thin-sheet-metal structures" when he considers that in the larger type airplanes practically no metal thicker than 1/16 in. is ever used.

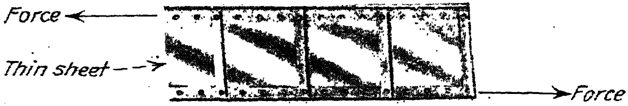


FIG. 116.—Shear in thin sheet changes sheet to a tension field.

2. *To show* how these fundamental principles (of item 1) are made use of in each of the airplane parts.

3. *To present a summary,* for ready reference, to be used by the mechanic in estimating the safe requirements for the repair of any part of an airplane.

146. Basic Stresses.—The stresses which any structure may be required to withstand are:

1. *Tension.*—This stress tends to stretch the member and thus make it longer.

2. *Compression.*—This stress tends to compress the member and thus make it shorter. In *thin-sheet-metal structures* the effect of a compressive stress is often difficult to analyze, since it involves the *stability of the structure.*

NOTE: *Stability* means resistance against buckling or wrinkling.

In thin-sheet-metal structures, members never develop their full compressive strength. They always fail by *buckling or wrinkling,* at a stress very much lower than their *compressive ultimate strength.*

3. *Shear.*—This stress tends to slide one layer of fibers over the adjacent layer. Rivets are always in single or double shear. Thin sheets do not transmit shear very well. The shear changes the thin sheet into a tension field as shown in Fig. 116.

4. *Bending.*—Bending is a combination of tension, compression, and shear. The tendency to bend is caused by a bending moment, that is, a load applied in such a manner that the beam is bent.

147. Theory of a Monocoque Structure.—Consider a tube of small radius r_0 and excessive wall thickness t_0 (Fig. 117*a*). The tube may be used as a strut, as a torque tube, or as a beam. Now obtain another tube of the same weight, length, and material, the radius of which is $2r_0$ (see Fig. 117*b*). The thickness of the wall will then be $t_0/2$. This beam will be four times as strong, either as a strut, as a torque tube, or as a beam. The tube is also four times as rigid in torsion and bending. The natural question to ask now is: What is the limit of this process of increasing the diameter and decreasing the wall thickness? The answer is that a new element is introduced which limits the process,—the wrinkling of the thin metal.

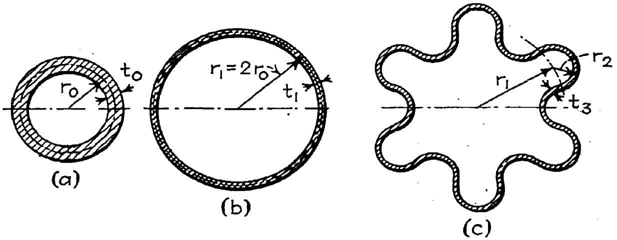


FIG. 117.—Increasing the strength of a tube without increasing its weight.

148. Wrinkling of Thin Sheet Metal.—Wrinkling is a form of *instability*, just as the buckling of a strut is a form of instability of the structure. *Buckling, however, pertains to the entire member of the structure, and wrinkling pertains to a local condition.*

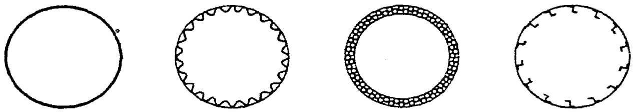
A buckle, by increasing the stress locally, may cause the strut to fail in wrinkling; and likewise, a wrinkle may cause the strut to buckle. Obviously, the ideal condition in this case is to make the strut of equal strength in wrinkling and buckling, *which can be accomplished quite readily in design.*

The larger the radius becomes and the thinner the sheet becomes, the less will be the load which can be applied without wrinkling.

Figure 116*c* shows a scheme for keeping the radius of curvature of the sheet small to prevent it from wrinkling. The thin sheet in Fig. 117*c* is corrugated.

Figure 118 shows a number of variations and extensions of this idea of corrugating the sheet metal. In (*a*) we have the solid shell or tube. In (*b*) a corrugated inner tube is used to prevent *wrinkling*, and a thin outer sheet is used to obtain a smooth surface—and as we will find later, to add strength in torsion because a corrugated tube is weak in torsion. *The corrugations have a tendency to fold up under torsional stress.*

Figure 118*c* shows another extension of the idea of corrugations; that is, strength against wrinkling is obtained by using a nest of very thin-walled, small-radius tubes. This is a *cellular* structure. Figure 118*d* shows still another variation which is the most commonly used. The thin outer sheet and strips of reinforcing metal form a mutually supporting unit. These strips are called *stringers*. Figure 125 shows nine types of stringers in common use. Our structure at this stage changes its name to *semimonocoque*. Figure 118*e* shows a variation of the stringer idea. The stringers are placed in double spirals.

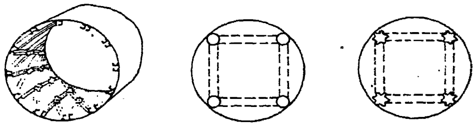


(a) Monocoque (Solid shell)

(b) Monocoque (Corrugated)

(c) Monocoque (Cellular)

(d) Semi-monocoque (Stringers)



(e) Semi-monocoque (Geodetic)

(f) Tubular longerons (Frame structure)

(g) Corrugated longerons (Frame structure)

FIG. 118.—Structural types.

In Figs. 118*f* and 118*g*, the stringer idea is carried to such an extreme state that the structure has reverted back to a tubular longeron frame.

149. Illustration of a Monocoque Structure.—The facts given in the last few paragraphs may be simply illustrated by rolling a sheet of stiff paper around circular blocks, as illustrated in Fig. 119, and gluing the free edges of the paper and the blocks. The blocks are placed in their positions so that *concentrated loads may be applied to the structure at the blocks.* These loads would wrinkle the paper if the blocks were not there to prevent this local failure.

Figure 120 shows the application of the principal types of loading to the structure. *Tension* is not shown because it is not a serious problem in monocoque structures. The thin sheet develops its full ultimate strength in tension. The design strength for the other three types of loading is so low that *tension is very rarely the determining factor in the thickness of the sheet or in its structural arrangement.*

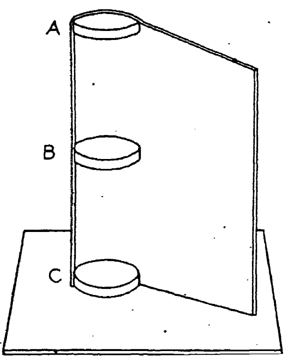


FIG. 119.—Paper rolled around three bulkheads, *A*, *B*, and *C*.

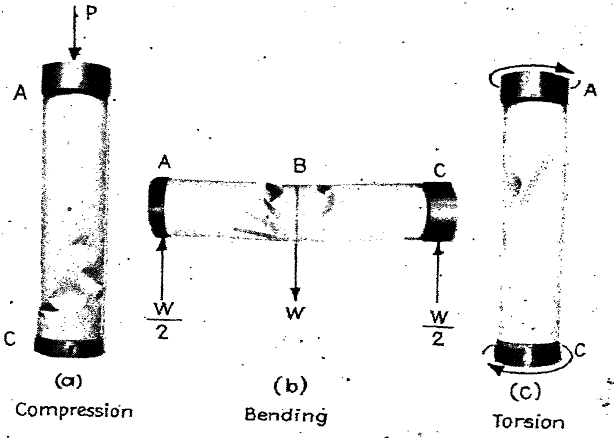
A demonstration of the *remarkable efficiency* of a monocoque structure may be arranged as follows: Get a small can of pork and beans, or a similar can; place it on end; balance a board on top, then have several students stand on the board. Note that the thin wall of the can *carries the entire load.* This is a true type of monocoque structure.

Figure 120*b* shows the paper monocoque tube carrying a bending load. Note that the direction of the wrinkles indicates tension directed to support the center block (bulkhead).

Figure 120*c* shows the tube subjected to a torsional load such as exists in the torque tube of an aileron or elevator. Figure 121 explains the cause of this particular type of wrinkle. The shear force, as noted in (*a*), has a tendency to divide into two components, compression and tension, at 45 deg. to the plane of shear and at 90 deg. to each other. It is the compression component that collapses the thin sheet, as will be seen by comparing Figs. 120*c* with 121*b*.

150. Bulkheads and Reinforcing Rings.—Structures performing the functions of blocks *A*, *B*, and *C* (Figs. 119 and 120) are called *bulkheads.* The primary function of a bulkhead is to receive concentrated loads and to distribute the concentrated loads evenly into the thin walls of the monocoque structure.

A concentrated load causes a local failure in the thin sheet metal; that is, the metal dents or wrinkles under the load.



(a) Compression (b) Bending (c) Torsion

FIG. 120.—Wrinkling of monocoque structure.

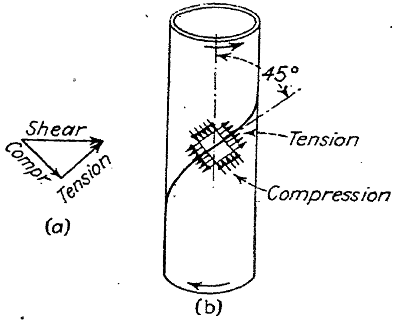


FIG. 121.—Stresses in torsion.

The primary precaution to be observed in repairing monocoque structures is to avoid concentrated loads which will cause local failures.

Bulkheads and *reinforcing* rings are used mainly for this purpose just as the blocks were used in the paper tubes. We note, in this connection, that the following monocoque structures are tubes: wings, fuselage, engine nacelles, and control surfaces. If the control surfaces are not themselves tubes, they are built around tubes. Thus we find *bulkheads* and *reinforcing rings* used for the following purposes:

1. *Attaching a Fuselage to a Wing.*—In this case we have two tubes at right angles to each other. Figure 122*a* shows the method; the wing tube has bulkheads *AA* to which are attached fuselage-reinforcing rings *BB*. Figure 122*b* shows the arrangement of the wing and fuselage bulkheads for a wing passing through the center of the fuselage.

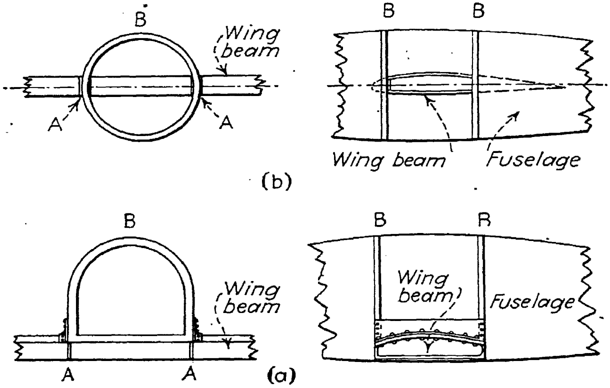


FIG. 122.—Fuselage-wing connection through bulkheads.

Each manufacturer has his own variation of the bulkhead idea. In some cases the wing tips are monocoque, and the center section is built on massive spars. The spars take the place of the wing bulkhead in this case. In such a structure a neat problem develops in distributing the concentrated loads from the spars into the monocoque wing section.

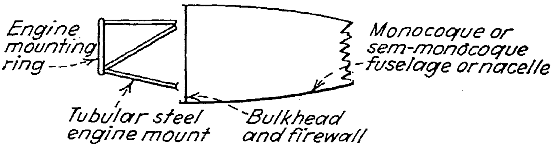

Engine mounting ring
Monocoque or sem-monocoque fuselage or nacelle
Tubular steel engine mount
Bulkhead and firewall

FIG. 123.—Attachment of engine mount to nacelle or fuselage.

2. *Attaching an Engine Mount to an Engine Nacelle or to a Monocoque Fuselage*—As noted in Fig. 123, a bulkhead is fitted into the end of the nacelle or fuselage, and the fittings are attached to this bulkhead. The skin adjacent to the bulkhead is often reinforced for a few inches by a thicker skin to further distribute the loads and to prevent local failures where the stresses may be concentrated.

3. *Attachment of a Stabilizer or Vertical Fin to the Fuselage.*—Figure 124 shows the fundamental idea used for this connection. The bulkhead as an integral part of the fuselage carries the fittings for the empennage-surface spars. In some cases the spars are an integral part of the bulkhead, as noted in the figure.

4. *Attachment of a Monocoque Engine Nacelle to a Monocoque Wing.*

5. *Attachment of Control Surface Hinges to Monocoque Wing.*

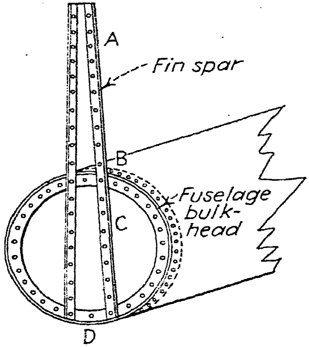


FIG. 124.—Bulkhead for attaching vertical fin to fuselage.

151. Rigidity of a Bulkhead or Reinforcing Ring.—If, for example, the bulkheads in the paper tubes of Fig. 120 had been made of sponge rubber, their purpose would have been defeated. The paper would have been readily dented by the loading string, so that its strength would have been decreased to practically zero. We thus conclude:

Bulkheads and reinforcing rings should be rigid enough to carry the concentrated loads with a minimum of deformation. The true shape of the monocoque structure must be maintained to develop its strength.

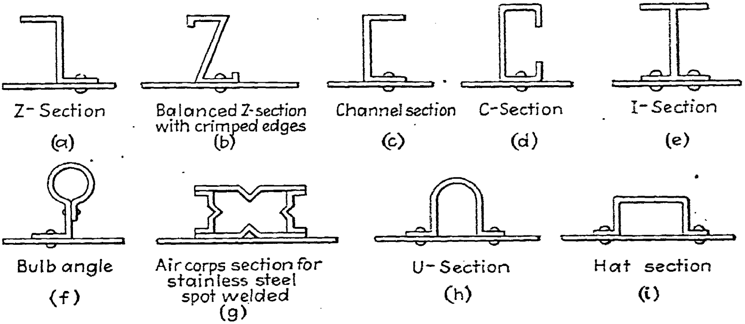


FIG. 125.—Typical stringer sections.

As noted later, this is the principle fact to be observed in the repair of a bulkhead or reinforcing ring.

152. Semimonocoque Structures.—Very seldom is the true monocoque structure found in an airplane. This is because the thin sheet metal for large diameters will carry only a small compressive load without wrinkling. Some other device must therefore be used to carry the compressive loads. The idea of the corrugated structure gives the clue to another scheme namely, to obtain the advantages of corrugating the sheet and yet to retain its smooth exterior surface. The scheme is to rivet strips of corrugation or stringers to the inside as shown in Figs. 118*d*, 125 and 137.

A structure which is composed of a monocoque shell, reinforced by stringers, bulkheads, reinforcing rings, formers, and other stiffening members is called a semimonocoque structure. Figures 118, 126, and 138, show such structures.

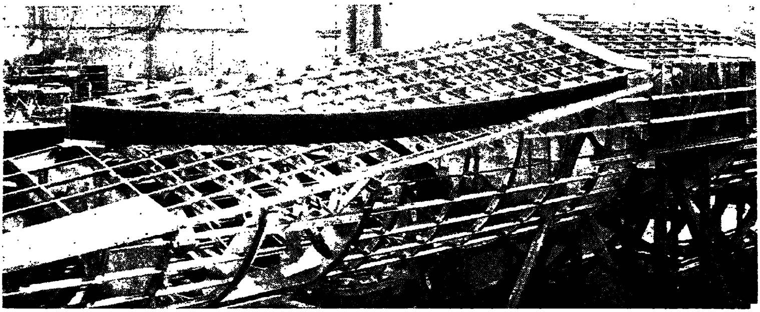


FIG. 126.—Semimonocoque structure. (*Courtesy of Glenn L. Martin Company.*)

153. Strength of Stringers.—As noted in the previous paragraph, *stringers are designed to carry the compressive load in a semimonocoque structure.* (In this connection, the students' attention is called to the loads in bending, Par. 160.) Stringers also carry tensile loads, but these loads, in general, are only a small fraction of the ultimate tensile strength of the metal. In fact, the tensile stress is so easily provided for that *practically the entire design problem is in stiffening the structure to carry compression.*

In a stringer, curved-sheet combination such as is found in the fuselage, and sometimes in the wing and in other parts of the airplane, it is difficult to determine whether the stringers should be designed to stiffen the sheet, so that it would be able to carry a heavier load, or whether the stringer should be assumed to carry the load and the skin to support the stringers. The tendency has been toward the latter choice, that is, to make the skin as thin as practical and to design the stringers to carry the compressive load.

154. Failure of Stringers.—Figure 127 shows the typical failure of stringers. All the failures come under the general class of local wrinkling due to an excessive compressive load.

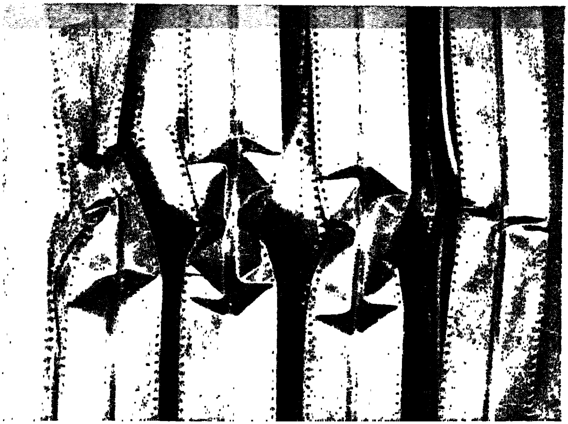


FIG. 127.—Types of failures of stringers. (*Courtesy of U. S. Army Air Corps.*)

In the repair of a stringer, therefore, we conclude at once that the repair should be such as to prevent local wrinkling. (See Job Units Nos. 30 and 31 for further discussion and instructions.)

155. Holes and Slits in Monocoque Structures.—A hole cut in the wall of either of the tubes of Fig. 120 will ruin their strength. However, by gluing a cardboard rim, cut to fit, around the hole, the strength of the tube may be regained. The wider and thicker the frame of cardboard, the stronger is the reinforced structure.

Thus it becomes apparent that a handhole, window, or door in a monocoque structure must be encircled by a reinforcing structure.

In some cases it may be necessary to get to the inside of a structure where no opening is available to make repairs. If the mechanic understands the structural requirements involved, he may cut a handhole, and then, after the job is finished, repair the handhole with a frame of thicker metal to preserve the monocoque structure. To cover the hole, a cover plate may be screwed to the frame. (See Job Unit No. 41 for details.)

If the tube of Fig. 120*c* were split along an element (parallel to the axis), it would lose its torsional strength. *Thus to have torsional strength, the circumference of the cross section of a tube must be continuous.* If the circumference is not continuous, then a bracing structure must be built in across the opening to maintain torsional rigidity.

Thus a monocoque engine nacelle with the bottom cut out to accomodate the retracted wheel requires special bracing to retain its torsional strength.

It was once considered in monocoque (stressed-skin) wing design that "cutouts" could not be made to receive gas tanks. *The logical answer, is to make the gas tank a part of the wing.* This is now being done in some modern designs.

156. Shear Loads.—In general, all shear loads in a semimonocoque structure are carried by the thin sheet metal. In design, the metal is expected to wrinkle some under a load less than half of its design load. The wrinkles will disappear when the load is removed, if the structure has not been overstressed. A permanent set in a wrinkle should be inspected carefully for signs of failure in other parts of the structure. Repairs will probably be necessary.

157. Engine Mount.—A monocoque engine mount has proved impractical. This is because parts of the engine should be accessible from the outside. *Holes cannot be cut in a monocoque structure without great reduction in its strength.* A welded steel structure has proved more practical. In such a structure the loads are concentrated along the tubes of the structure.

158. Cracking of Engine Mount and Nacelle Skin.—A monocoque structure is extremely rigid, and hence will allow only a small movement when vibrated by the engine. If the engine is held too rigidly, excessive stresses are set up in the nacelle structure, which will soon cause the skin to crack. *To relieve these stresses, and to cut down vibration and noises from the engine, the engine mount is usually set in rubber, or some other resilient material.*

Since there is some torsional movement in the engine-mount structure, the cowling of the engine mount, if clamped too tightly to the structure, will tend to carry the load. Hence a high stress is introduced, which soon results in cracking of the cowling. Allowance should be made in the cowl fastenings for the torsional motion of the engine mount.

159. Fundamental Parts of a Wing Beam.—In order that we may later understand the repair of beams, it is necessary to learn the principal parts of a beam, and requirements of those parts in assisting to carry the loads.

The function of a beam is to carry a bending load. Let us begin with the most elementary case and proceed in our study to the most complicated cases of wing beams.

160. Bending.—Bending is a combination of tension, compression, and shear. For example, refer to Fig. 128. In (*a*) the load W causes the beam to bend. The bending tendency is called the bending moment. In this case the bending moment at B is W times x. If W is in pounds and x is in inches, the bending moment at B is Wx lb.-in. For example, if W is 100 lb. and $x = L = 40$ in., the bending moment is $100 \times 40 = 4{,}000$ lb.-in.

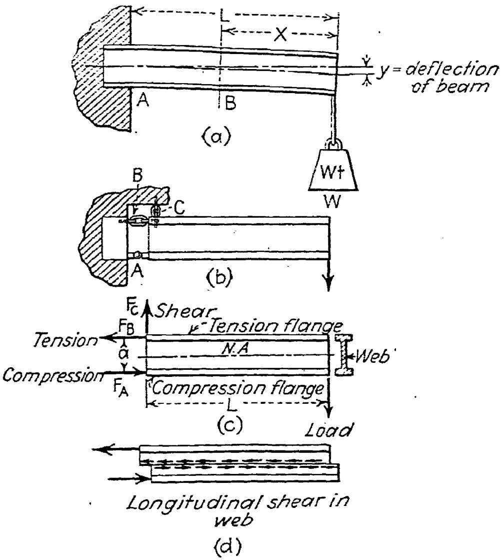


FIG. 128.—Forces resisting the bending of a beam.

Now if the beam is cut across at A as in (*b*), the supports A, B, and C must be supplied to hold the beam in place. If we represent these forces by arrows, called vectors, we have what is called a "free-body diagram," as shown in (*c*). In this diagram, F_A

is the compressive force, F_B is the tensile force, and F_C is the shear force.

161. Parts of a Beam.—As noted in Fig. 128*c*, the portions of the beam which carry the tensile and compressive stresses are called flanges, and the portion which carries the shear stress is called the web. The line *N.A.* is the dividing line between the tensile and compressive stresses. It is called the *neutral axis.*

This *neutral axis* of a beam can be very easily located, by theoretical calculations, but the following simple method requires no skill and is, in general, just as accurate:

1. Take the dimensions of the beam, such as width and depth of flanges, width and depth of web.
2. Lay these dimensions out on a stiff cardboard—the cross section of the beam.
3. Cut the cross section out of the cardboard.
4. The center of gravity of this cardboard is the neutral axis of the cross section.
5. If the card is balanced on a pencil, the line of contact with the pencil is the location of the neutral axis.

The shear along the neutral axis is a maximum (see Fig. 128*b*). If the web is thick, it carries some of the compressive and tensile stresses, but in thin-sheet-metal structures the web is quite thin and actually carries very little tensile stress, and no compressive stress. It is generally assumed to carry only shear. The total horizontal shear in this case is ($F_B = F_A$). We note also that the bending around the point A is WL, which is balanced by F_Ba. If we assume that a is 5 in., we have, if $L = 40$, and $W = 100$, the equation $5F_B = 40 \times 100$, or $F_B = 800$ lb. If the thickness of the web is 0.1 in., the shear area is $40 \times 0.1 = 4$ sq. in. The average shear per square inch is $800 \div 4 = 200$ lb. per square inch.

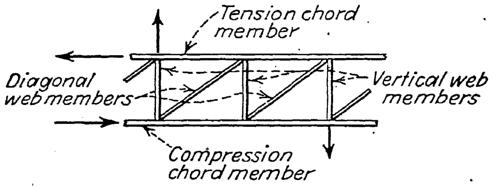


FIG. 129.—Parts of a trussed wing spar.

162. Trussed Beam.—In trussed beams (see Fig. 129) the flanges are called chord members. The functions of the web are performed by vertical web members and diagonal web members. In Fig. 129, the *diagonal* members are in compression and the vertical members are in tension. If the loading were *reversed,* the diagonal members would be in tension and the vertical members would be in compression. Since a wing beam is subjected to both up and down loads, all parts are designed for both tension and compression.

163. Gusset Plates.—A gusset plate is a plate of metal inserted in the joints of a truss to provide sufficient area for riveting the members at their intersection. Figure 130 shows a gusset plate used to connect the chord, diagonal and vertical members of a trussed beam. The loads imposed on the plate are obviously those provided by the intersecting members. The rivets must possess sufficient strength to carry the loads imposed by the members.

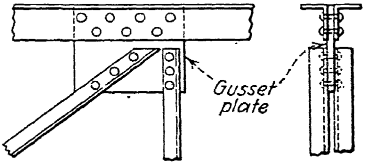


FIG. 130.—Gusset plates.

164. Beams with Thin Webs.—Beams with thin webs are generally used in stressed-skin wings. Figure 131 shows such a beam. As will be noted later, vertical web members, as shown in this figure, are a necessary part of a thin web.

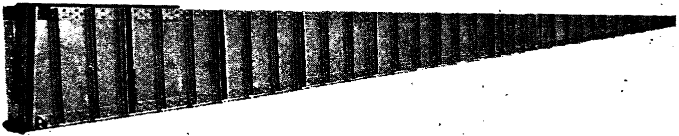


FIG. 131.—Beam with thin web. (*Courtesy of Glenn L. Martin Company.*)

Figure 132 shows the disposition of the forces in a thin web. The web of course, as we have noted previously, carries the *longitudinal shear* between the *tension* and *compression* flanges of the beam. AB in (b) show a vector of this shear acting on a unit area of the web, as shown in (a). Shear, however, has two components, tension AC and compression CB. This is indicated in (a) and in (b).

The thin sheet, however, wrinkles under the effect of compression, as noted in Fig. 133. The beam in this figure is supported at the ends and the load is applied at the center. The web shear on one side of the load is opposite to the web-shear load on the other side.

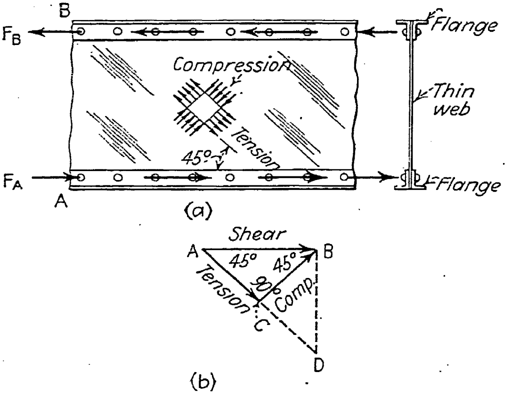


FIG. 132.—Stresses in a thin web.

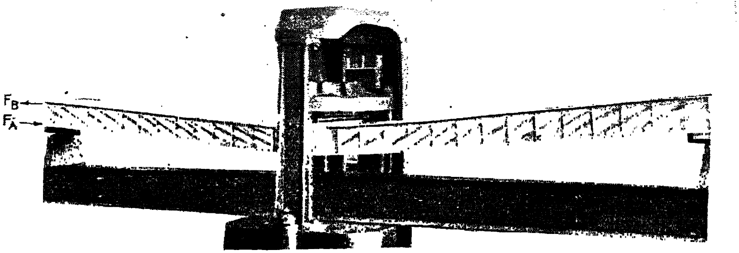


FIG. 133.—Shear in thin webs of a beam. (*Courtesy of U. S. Army Air Corps.*)

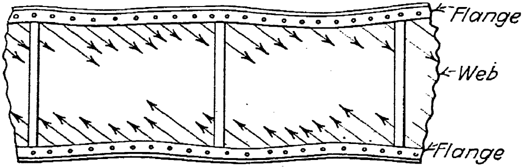


FIG. 134.—Bending of flanges in a thin-web beam.

Since the compression component of shear in Fig. 132*b* offers little resistance, the *tension component must carry the shear.* This is indicated by *AD*.

165. Webs Assumed to Wrinkle.—A thin web will wrinkle under a light load, but when the load is removed, the wrinkle will disappear. It is assumed in the design, that the webs will wrinkle under load; and they are designed on that basis. A beam of this kind is quite strong, but a slight deterioration in the web very rapidly saps its strength. The constant wrinkling as the wing passes through "bumpy" air introduces fatigue stresses in the thin plate; *this is extremely bad*. Also unless the beam is well designed, the tension of the web tends to pull the flanges together between the vertical web members, as shown in Fig. 134. The binding of the flanges relieves the stress on the rivets between the vertical web members; and, since a total shear must be resisted, the rivets at the intersection of the vertical member and the flange carry the greater part of the load. This is indicated by the length of the arrows in Fig. 134.

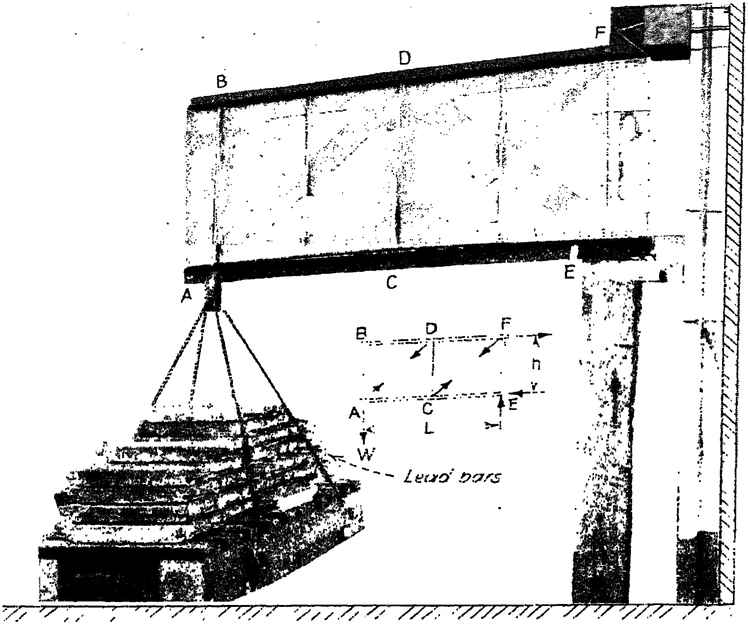


FIG. 135.—Static-testing a section of a 55-ft. wing beam. Note tension lines and buckling of vertical members. (*Courtesy of U. S. Army Corps.*)

Figure 136 shows the result of this condition.

166. Webs Assumed Not to Wrinkle.—A nonwrinkling web is in general more satisfactory than a wrinkling web, but it is heavier. The stresses, of course, will be less in a nonwrinkling web, because thicker material will be required. *Repair will be simpler because of the lower stresses.*

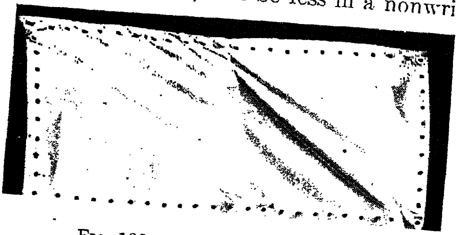
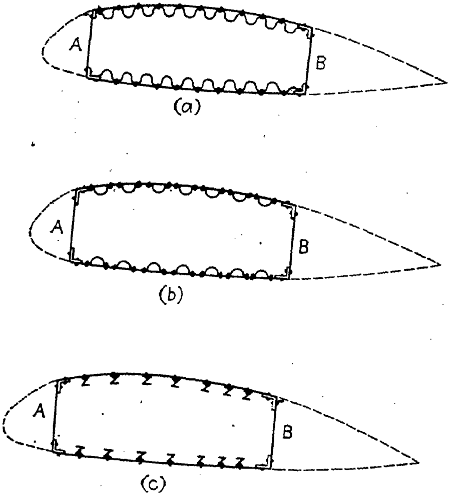


FIG. 136.—Failure of a thin web.

Sometimes a diagonal member is used with the thin web to carry the heavy flying loads in tension. The thin web is assigned the inverted flight load, which it carries in tension, assisted by the compressive load in the diagonal. The tension in the thin sheet braces the diagonal against buckling. This makes a rigid, light,



(a)

(b)

(c)

and strong structure, and one easily repaired. (See Job Unit 37 for repairing details.)

167. Box Beams (see Fig. 137).—A box beam has two webs, *A* and *B*, which together with the flanges form a box. In such a beam, the vertical members are generally bulkheads on the inside of the beam. In many of the modern all-metal monoplane wings, the entire wing, excluding the leading and trailing edges is the box beam (see also Fig. 138). *In such a wing the flanges are the upper and lower surfaces of the wing.* The two webs of the box beam assume the usual position of the wing spars. They are not spars, however, and they do not assume the same function as spars.

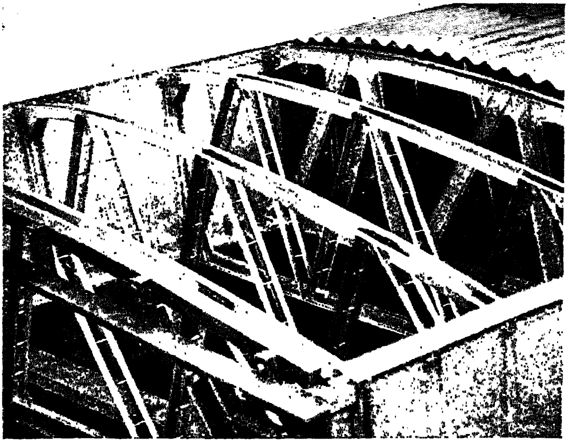


FIG. 138.—Box wing beam with corrugated flanges and thin webs. (*Courtesy of the Glenn L. Martin Company.*)

Since the flanges of this type of wing beam (sometimes called a shell-type wing, or stressed-skin wing) must carry a heavy compressive load, some provision must be made to prevent the thin sheets from wrinkling or buckling. *The ribs of the wing—which in this type of structure are the bulkheads—afford bracing of the flanges against buckling* to some extent, by making the equivalent strut length shorter. To prevent *wrinkling*, the metal is sometimes *corrugated.* If the metal is left smooth, then longitudinal stringers of some type must be inserted to carry the compressive load. (See, for example, Fig. 139.)

168. Stiffness of a Box Wing.—The box or shell type of wing has great torsional stiffness. *In this respect it is a tube.* It will be noted that a large-diameter tube is quite stiff in torsion. Stiffness is not strength, however. A paper tube is quite stiff, but has little strength. Stiffness is important to a wing to prevent wing flutter at the high speeds of modern airplanes.

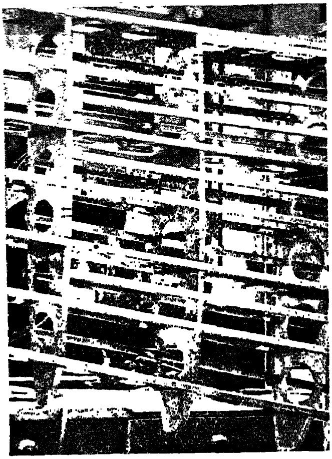


FIG. 139.—Stringers in a wing tip.

169. Multispar Monoplane Wings.—All modern monoplane all-metal wings are not box wings. Some metal wings are built on *spars*, which run the length of the wing. Ribs transmit the load from the metal skin to the spars. The *skin* of such a wing, however, is generally *stressed*, as it carries the shear stress for the chord load, that is, the load parallel to the chord. For this load the spars act as flanges for the wing as a box beam, and the skin acts as the webs. The skin also gives the wing great torsional stiffness.

170. Single-spar Wing.—Some of the modern all-metal wings have only one spar. This type is called a *monospar wing*. Such a wing can be made equally as strong as a *multispar* wing. To give the wing the proper torsional rigidity and strength, the nose section together with the spar are made to constitute a large tube (see Fig. 140). We have previously seen that a thin-walled tubular section such as this has great rigidity; and the required strength may be designed into the structure. *The trailing edge*

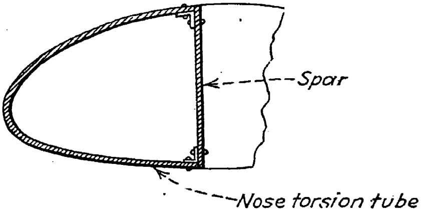


FIG. 140.—Monospar wing section.

of such a wing may be of fabric for lightness since it does not help support the wing. The only strength required is the rib strength to carry the trailing-edge load to the spar.

171. Wing Connection.—A wing connection such as the connection between a wing-tip section and a center section provides for the transmission of the tensile and compressive stresses in the flanges and for the transmission of the shear stress in the web. If the wing is built on trussed spars, the connection simply consists of fittings at the ends of the chord members which will transmit the load in the chord members. The truss of the center section and also the truss of the tip section will have a vertical-web member at the joint. Thus two web members will be functioning side by side at the joint.

In a box-type, stressed-skin wing, it is also necessary to make the connection in such a way that the *thin skin will not wrinkle* at the connection. *A very small uneveness in the fitting may throw a heavy concentrated stress in the thin sheet, unless this is amply provided for.*

A *stiffener* or *bulkhead* ring serves the purpose of distributing the stress smoothly into the skin. The skin also is generally reinforced for a few inches from the fitting to prevent *local wrinkling* and further to distribute the stress.

If the box-wing flanges have stringers to carry the compressive load, the stringers may terminate in a rigid bulkhead ring at the joint ends of the two sections. This ring evens the loading in the stringers, and provides for a joint connection. Some wings do not have this ring but make the connection by an individual fitting on each stringer. This type of connection, of course, makes the stringer continuous. The fittings in this case must be ground to fit. A high spot of 0.01 in. or less will throw an unduly high stress in the stringer affected.

A heavy reinforcement at each of the free ends of the web at the joint will provide for the shear stress in the web. Across this joint, then, the shear will be transmitted through the flange connections. Also a plate may be used to connect the free ends of the webs. In this type of connection the shear in the web is transmitted through the plate as though it were a part of the web.

172. Bending of a Semimonocoque Fuselage.—The semimonocoque fuselage is a tube. When such a tube is bent, all the elements of a beam are manifested. In the upper and lower stringers, with reference to the bending load, the stress is *tension* and *compression*. The sides of the tube perform the function of the web of a beam, and carry the shear load. The reinforcing rings hold the fuselage in its true shape and support the stringers.

When the fuselage is bent sideways, as in turning, by a rudder load, the sides of the fuselage become the flanges of the beam, and the top and bottom of the fuselage perform the functions of the web of a beam and carry the shear. Under this type of loading, the door of the fuselage cuts the flange portion of the beam entirely across. However, the structure around the door is designed to carry this load, and to transmit it around the top and bottom of the door. (See Par. 155 for principle involved.)

The windows are treated in the same manner as the doors, so that the stress is transmitted around them through the window frame.

173. Flexibility of a Structure.—*All structures have some degree of flexibility.* An airplane structure, when the airplane is in motion, is subject to constant distortional movements. The wings bend in varying degrees, as they pass through "bumps" of air, and as the ailerons perform their functional duty. The empennage twists and bends the fuselage. The engine vibrates the nacelle and the wings. In general, however, these motions cannot be detected by the eye. What does all this mean to the mechanic? Simply this: *Rivets are working loose, cracks in the metals are developing, and undue loads are being thrown upon light members.* Let us consider an example of this last statement: When a wing bends, high stresses are thrown into the flanges of the spars, or in the flange portion of the box wing. According to Young's law of elasticity, the strain is proportional to the stress. *It is apparent, therefore, that the wing skin over the flange portions of the wing beams, since it is subject to the same strain as the flange, has the same stress.* When this stress is still quite low, the skin will begin to wrinkle. *Apparently* the wing is about to fail, but practically it may not be developing a tenth of its strength.

In some light structures on an airplane, not designed to carry stress, provision is made for relieving the stress by the use of sliding joints, or slits or gaps in the structure, to absorb the movement of the main structure.

If a light portion of a structure seems to be cracking unduly, it is probably carrying a load which it is not intended to carry.

174. Buckling of Compressive Members.—As noted in Par. 146, compressive members may fail by wrinkling locally or by buckling. Buckling is the bending of the entire member, as shown in Fig. 141. Because of the type of failures in each, struts (compressive members) are classified as long struts and short struts.

A *long strut* is one which is so long and slender that it will buckle under a load which is so low that the material will not *crush* or *wrinkle* locally. *Its strength does not depend upon the strength of the material but rather on how stiff the material is;* that is, it depends upon the *modulus of elasticity* of the material of the strut.

A *short strut* is one which is so short that it will not buckle except as a result of wrinkling the material locally.

It will be noted, therefore, that in the *repair of struts* the mechanic must give attention to both *buckling,* and local *wrinkling.* It is not necessary to know the dividing line between long struts and short struts as the repair of the two types require about the same treatment.

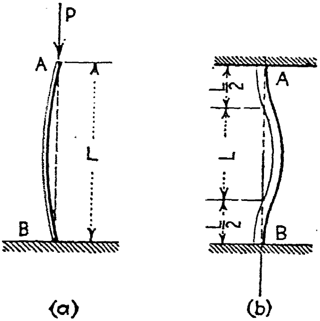


FIG. 141.—Buckling of struts.

In determining the nature of the repair job, the following outline of how to make a strut strong will prove of value:

1. The strength of a strut is *inversely proportional to the square of its length.* For example, if a strut is braced to a rigid frame at the middle of the strut, the effective length is cut in half. The strength, therefore, is increased four times.

2. *The strength of a strut is increased by fixing the ends rigidly.* For example, as noted in Fig. 141*b*, fixing the ends, is equivalent to cutting the length in half. The fact that the end of a strut is welded or riveted to gusset plates does not imply that the end is fixed, because the entire structure at the joint may move to allow the strut to bend. See for example Fig. 142: In this truss, the chord member and vertical web members of the truss assist each other in buckling. In general, if the ends of a strut are fixed, it may be safely assumed that the strut is doubled in strength.

3. *The strength of a strut is proportional to the modulus of elasticity of the material.* For example, for similar struts, duralumin and steel, the steel strut is three times the strength of the duralumin strut. (See Table II for the moduli of elasticity.)

NOTE: The steel strut is also three times as heavy as the duralumin strut.

4. *The area of cross section of the strut should be spread out as much as possible.* For example, consider two tubes A and B of the same weight. Assume that the diameter of B is twice the diameter of A. Tube B is then four times as strong as tube A if the wall does not wrinkle.

5. *There should be no free edges in the cross section of the strut.* For example, if a tube used as a strut is split, there are two free edges in the cross section. This greatly weakens the strut as the free edges will wrinkle easily. A channel section is not a good strut for this reason.

6. *The actual design stress in a strut is assumed to be not greater than the elastic limit of the material.* Thus for duralumin of ultimate strength of about 60,000 lb. per square inch and elastic limit of 40,000 lb. per square inch, the upper limit of the load which the strut is expected to carry may be computed by multiplying 40,000 by the cross-sectional area of the strut in square inches.

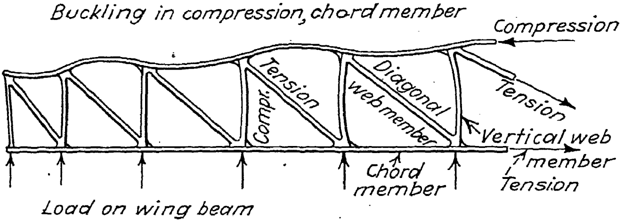


FIG. 142.—Buckling of fixed-end struts.

Review Questions

1. Name and define the basic stresses in a structure.
2. For what purposes are bulkheads used in monocoque structures?
3. Why is the rigidity of a bulkhead important?
4. Explain the reason for using corrugated sheet in a monocoque structure.
5. Draw sketches of ten types of stringers, and discuss the advantage and disadvantage of each type.
6. Explain the fundamental principles involved in attaching a wing to a fuselage.
7. Name the parts of a wing beam, and explain the function of each part.
8. Name the parts of a trussed wing beam.
9. Name the parts of a semimonocoque structure.
10. Name the factors affecting the strength of a strut, and discuss the effect of each factor on the strength of the strut.

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Questions for Thought and Study of References

1. What stresses must be provided for in a wing joint?

2. Describe the wing joints of the following airplanes with reference to the transmission of the flange stresses and the web stresses: Lockheed Lodestar, Douglas DC3, Boeing 247, Martin Bomber.

3. Describe the fuselage structure of the airplanes mentioned in question 2.

4. Describe the wing structure of the airplanes mentioned in question 2.

5. Describe the construction around a door of a semimonocoque fuselage for the transmission of stresses around the door.

CHAPTER X

FORMING THIN SHEET METALS FOR REPAIRS

Before studying this chapter, the student should study Par. 12, Sheet-metal Shop, which describes the equipment and the care of the equipment of a sheet-metal shop.

175. Grinding and Filing.—The aluminum alloys are seldom ground. Attempts to grind with the ordinarily used wheels merely clog the wheel, and burning of other metals will result when attempting to grind them.

A carborundum 3035 *will grind duralumin nicely.* This is a soft wheel that seems to clear itself well. For most work, hand filing is sufficient and has the advantage that there is less likelihood of leaving scratches or nicks.

176. Metal Forming.—There are many ways of forming metal into the complex shapes common to airplane construction. Sheets are rolled; angles, tubes, and other sections of the aluminum alloys are made by a process known as extruding; fittings and sometimes quite complex parts of considerable size are die forged. Other parts are formed in dies by a drop hammer or by large hydraulic presses. A great deal of ingenuity has gone into the development of manufacturing processes for the many parts that are needed. As this work is primarily intended for maintenance and repair, the above methods are not suitable on account of the excessively complex equipment required. Almost any forming, except forgings, can be done by simpler means, notably hand bumping.

Definition.—Bumping is the art of forming sheet metal into surfaces that are of complex curvature; that is, surfaces that include no straight lines or only straight lines that are relatively short.

Explanation.—Sheet metal can be curved in one direction without difficulty, but all such surfaces will include a series of straight lines that may be parallel, or may intersect at one or many points.

Bumping can be done either by hand or by machine.

177. Hand Bumping and Hand-bumping Tools.—In hand bumping, the metals are formed to the prescribed shape against dies or against yielding (such as sand bags) or nonyielding bodies by the application of many blows with hammers or other striking tools.

Striking tools are made of many materials, particularly of aluminum and its alloys.

Hammers are made of steel, wood, fiber, rubber, horn, rawhide, bakelite, and other materials. They are made in many shapes and styles. Choice of material is largely a matter of taste (see Figs. 143, 144, and 145).

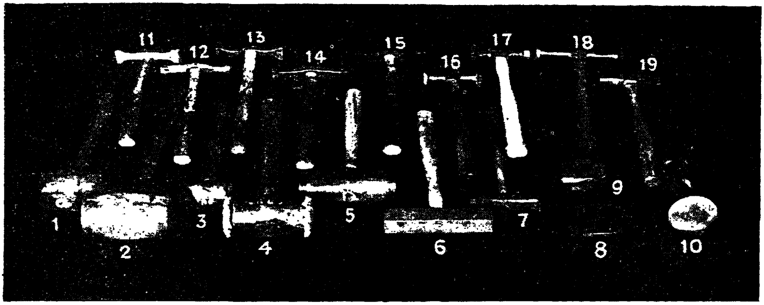

FIG. 143.—Bumping and dinging hammers: 1. Small soft-rubber mallet. 2. Large soft-rubber mallet. 3. Small rawhide mallet. 4. Large rawhide mallet. 5. Maple mallet. 6. Red-fiber mallet. 7. Small red-fiber mallet (may be made of Pyralin). 8 to 10. Steel hand dolly blocks. (No. 10 can be used with handle.) 11 to 19. Steel dinging hammers of various shapes. (*Courtesy of Boeing School of Aeronautics.*)

Mallets are made of soft (California) fiber or hard (red) fiber wood, or of rawhide. They are used for both heavy *roughing* and *finishing*. The shape of the striking face will depend upon the type of work. The *finishing mallets* will usually be kept nicely polished to prevent marring (see Fig. 143).

For some roughing work a *blackjack* is used. This tool is made of a long slender heavy leather bag filled with lead shot. It makes an excellent tool quickly to form the shapes wanted, particularly when used with some type of die (see Figs. 146 and 147).

Dinging hammers are used only for local work. They can be of almost any shape, size, and type. Most of them are double-ended and the head and face are shaped to force the metal into tight places (see Fig. 144).

Smoothing hammers have large flat or relatively flat striking faces and are used for the final finishing of the bumped work.

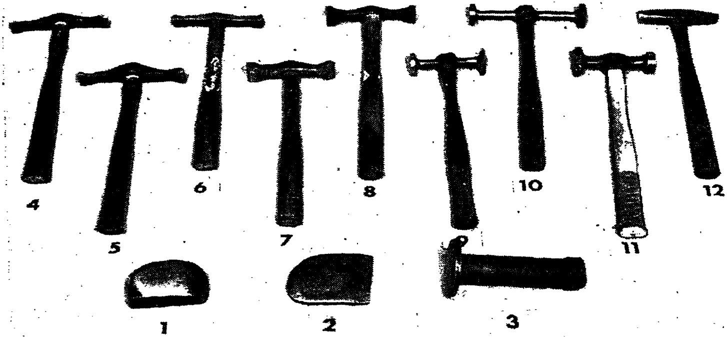

FIG. 144.—1 to 3. Steel hand dolly blocks. (No. 2 may be used on a handle.) 4 to 12. Assorted steel dinging hammers. (*Courtesy of Boeing School of Aeronautics.*)

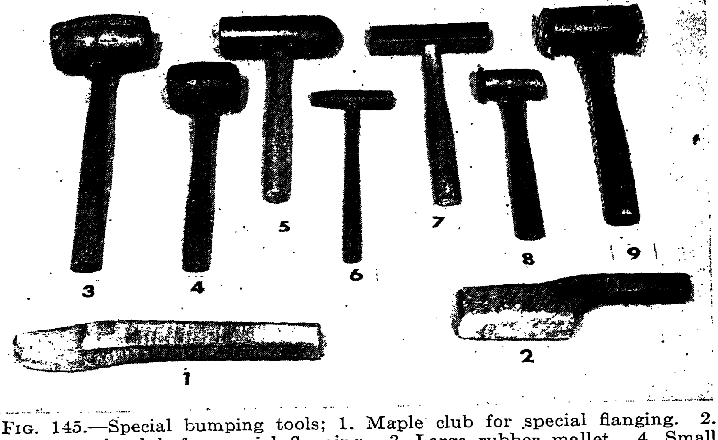

FIG. 145.—Special bumping tools; 1. Maple club for special flanging. 2. Another maple club for special flanging. 3. Large rubber mallet. 4. Small rubber mallet. 5. Maple mallet. 6. Small fiber hammer (may be pyralin). 7. Large fiber hammer. 8 and 9. Rawhide mallets. (*Courtesy of Boeing School of Aeronautics.*)

Sandbags for bumping are usually made of heavy canvas soaked in hot paraffin to close the pores and to lubricate the surface.

They can also be made of leather. They are usually about 18 in. square and 4 to 6 in. thick, and weigh about 50 to 60 lb. They may be larger or smaller than this.

Small parts are often bumped using the sandbags with mallets and hammers as the only tools.

A *blacksmith's swage plate* and several stakes and dollies will prove handy in working small parts.

Stakes are used for simple work. In the airplane shop, stakes are much simpler in form and much less used than in the ordinary tin shop.

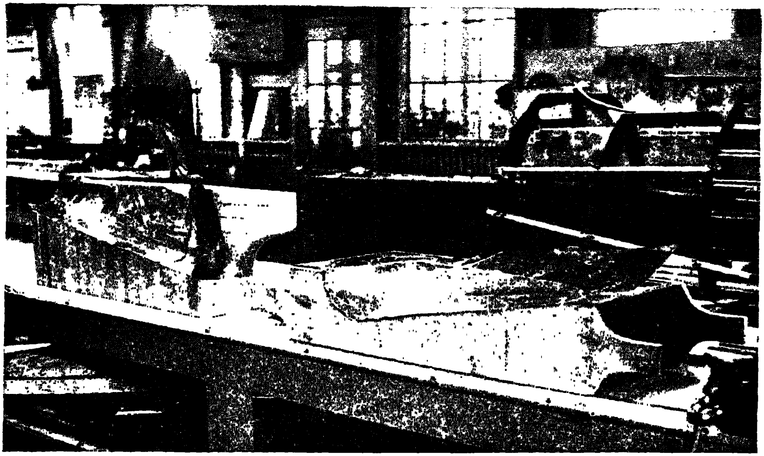

FIG. 146.—Left: Wooden form for bumping stabilizer fuselage fairing. Note leather blackjack on wooden form. Right: Concrete mold for bumping rudder boot. (*Courtesy of Boeing School of Aeronautics.*)

178. Bumping Dies.—Dies for hand bumping can be made in many ways and of several materials. Generally speaking, most dies are female but often male dies are most useful. It is often convenient to make a mold by casting a concrete block against a wooden pattern shaped to the form and size desired (see Figs. 146 and 147). After the concrete sets, it is lined with billiard felt and shellacked in place. The concrete should be made up of a rich mixture (2 to 1) of clean sharp sand and cement mixed sufficiently wet to allow most of the bubbles and voids to work out from the face of the pattern. If there are sharp radii or deep draws, the concrete should be reinforced around them with steel

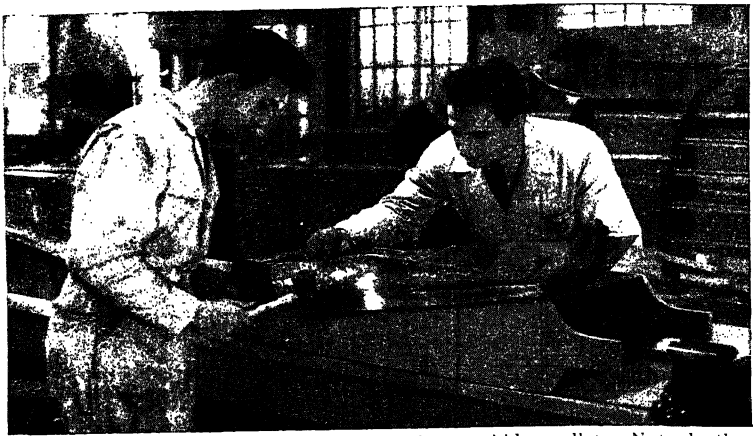

FIG. 147.—Bumping in concrete mold, using rawhide mallet. Note leather blackjack on metal at right. (*Courtesy of Boeing School of Aeronautics.*)

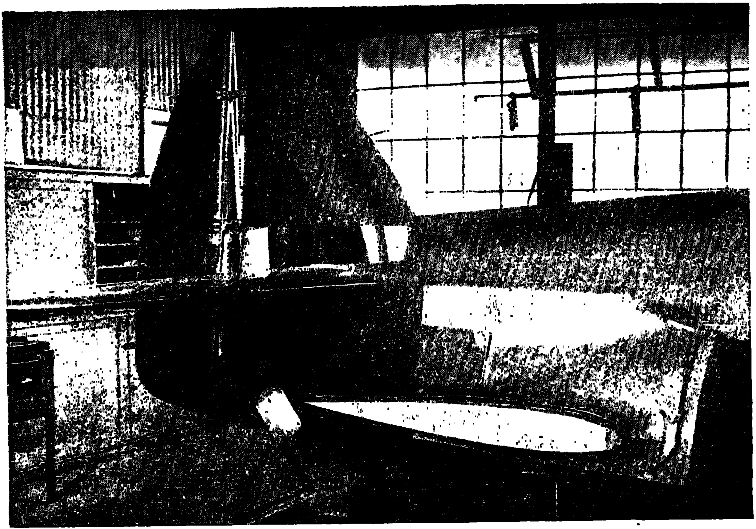

FIG. 148.—Aluminum fairing for fuselage fin shaped on wooden form. (*Courtesy of Boeing School of Aeronautics.*)

wire or rods. *The concrete should age for at least a week before bumping against it.*

In lining the concrete mold with felt, the material should be thoroughly wet and then formed over the wooden pattern. Tack it around the edges and allow it to dry thoroughly. It will then be found to fit the depression in the concrete block without wrinkles, and it can be shellacked into place. The shellac should be applied to the concrete. Apply one coat, allow it to dry, and then sand it. Apply another coat, and while wet put the felt into place.

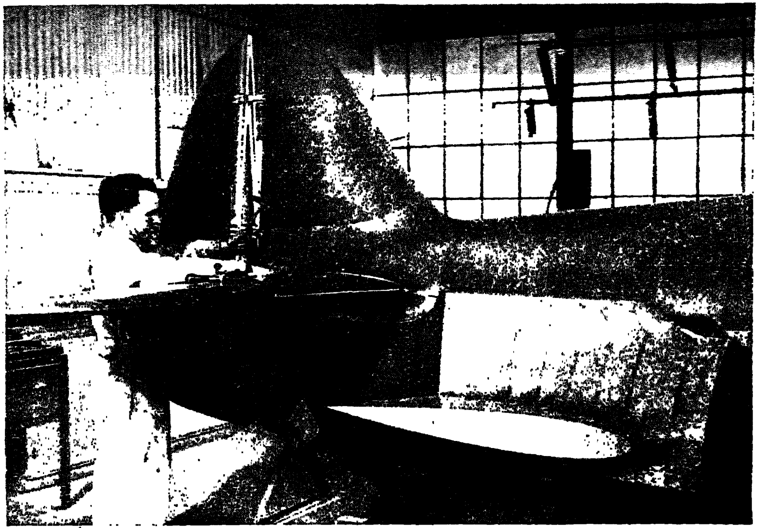

FIG. 149.—Aluminum fairing for fuselage fin. Picture shows use of fiber hammer in final fitting. (*Courtesy of Boeing School of Aeronautics.*)

Dies may also be made of wood. Any hard wood may be used. The wood must be physically *hard* but not necessarily hard by classification. *Maple* makes the best die, but it is expensive. Douglas fir is an excellent material. It is hard but is classed as a soft wood (conifer). (See Figs. 146, 148, and 149.)

In making wooden dies, boards, finished to about 2 in. thickness, are cut in sufficient number and size and glued together to obtain the volume required. The general form of the die can be closely cut on the band saw. The die is then shaped with gouges, chisels, and planes to the exact form. After smoothing, the wood should be shellacked with four or five coats. Each coat should be sandpapered when it is dry.

179. Process in Hand Bumping.—After the metal part is "hand-roughed" approximately to shape, the part can then best be smoothed in a light-power bumping hammer. *Very light blows* (but many of them) will smooth out the wrinkles and will not change the shape of the part too much. The part must be fit to the die frequently to check the size and shape of the part.

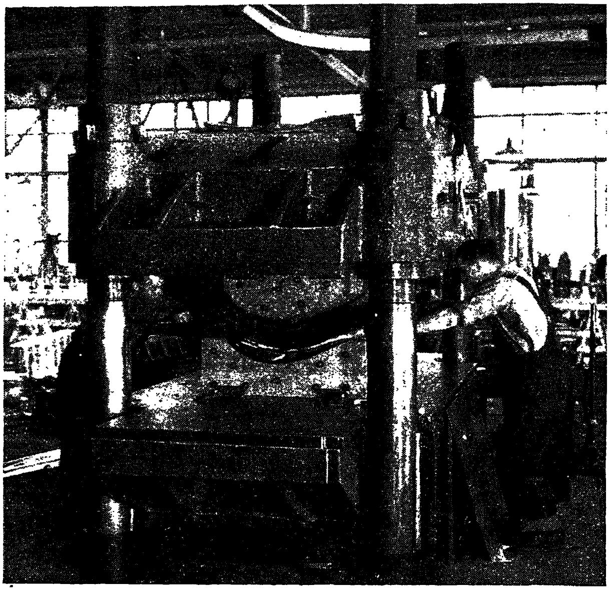

FIG. 150.—Use of heavy press with maple dies for forming thin-sheet-metal parts. (*Courtesy of Boeing Aircraft Company.*)

In bumping, many light blows are best, as too heavy a blow thins the material locally. In finishing, very light blows with light hammers are best.

When using the power hammer, lard oil is used on both sides of the material to prevent local seizing to the hammer or anvil. The hammer and anvil must be rounded off around the circumference, leaving a flat portion about the size of a quarter or a nickel. The surfaces must be highly polished.

180. Power Bumping.—Power bumping can be done by a power hammer. It requires, however, a much greater skill than does hand bumping. Skeleton moulds, or forms, can be used in power bumping, but the operator must be thoroughly skilled in their use in order to control the work. For this reason most power bumping is done by other means, as detailed below.

Hydraulic presses are used for production bumping in most airplane factories. The work is done in two general ways, either by using male and female matched wooden or metal dies (Fig. 150), or by using a male die with a heavy rubber blanket on the platen to force the metal to the die, as shown in Fig. 150. *Care must be taken to insure that there is sufficient displacement of the rubber to insure sufficient pressure and conformity.* Large spaces on the platen must be filled in with blocks of wood or other material. These blocks may be dies for small parts, which parts may be made at the same time the large part is pressed out.

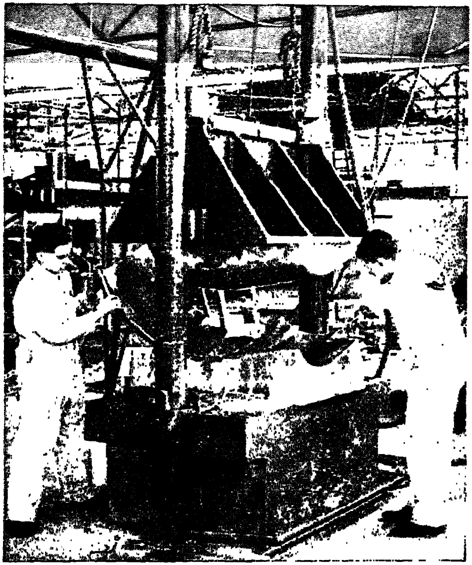

FIG. 151.—Drop hammer forming metal sheets. (*Courtesy of Ryan School of Aeronautics.*)

The rubber method is most suitable for shallow draws. The matched-die method will do for relatively deep draws.

Where many parts must be made or where exact conformity is necessary, the drop hammer is frequently used (see Fig. 151). Essentially, the drop hammer operates like a gravity pile driver. This type of hammer is raised by a rope and allowed to drop freely on the die.

Figure 152 shows how corrugations may be easily formed in flat sheet in a hand press or hydraulic press.

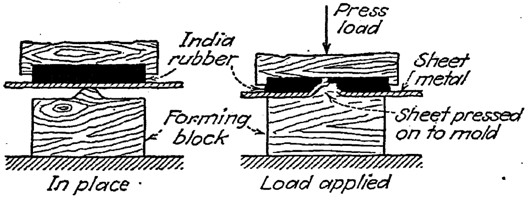

FIG. 152.

181. Dies for Power Bumping and Forming on the Drop Hammer.—Male and female dies are made as follows (the female die is usually placed on the anvil):

The part to be made in the die is modeled in dental casting plaster. A zinc block is cast against this plaster model. For limited production the zinc block will be placed on the anvil and leaded in place, holes being left in the anvil to key it. The hammer is then fitted with keying bolts and a form is built up around the zinc die. Melted lead is then poured into the zinc die, the hammer is lowered onto the lead, and the lead allowed to harden around the keying bolts.

When cool, the dies must be slightly *relieved* by hand to clear the part to be made.

Deep draws are made by using collars of varying thickness to limit the depth of the blow and to make the draw in several steps.

When the *drop hammer* is used for heavy production, the lead will be cast against the zinc die before it is mounted, and it will be located by bolting the lead die to the hammer; then the zinc die is leaded to the anvil.

The drop hammer (Fig. 151) is a process for the factory only, as but few if any repair shops will find sufficient need for it to warrant its installation.

182. Aluminum Alloys Used in Bumping.—The following outline shows the uses of aluminum alloys where bumping is required:

1. Alloys 2S and 3S for cowlings, fairings, and other nonstructural parts.
2. Alloy 2S for parts to be welded; it welds well.
3. Alloy 3S is much stronger than alloy 2S, so it would ordinarily be the preferred material.
4. For hand bumping, alloys 2S0 or 3S0 (dead soft) are used. When deep draws are made, it will be necessary to anneal the metal two or three times during the process.
5. Alloy 17S bumps the best of the structural materials; it does not warp as much in heat treating as other alloys. It must be annealed at 650°F. (carefully controlled), and then air-cooled.
6. Alloy 24S is more brittle, work-hardens more rapidly, but anneals the same as alloy 17S. As 24S is stronger than 17S, it must be used at times.
7. Alloy 52S is an alloy that does not need heat treatment but is lower in strength than 17S. It bumps better than 17S, but work-hardens nearly as much.

183. Bumping Structural Parts.—Bumping is but seldom used for structural parts. One reason for this is that it is necessary to heat-treat the strong aluminum alloys after such working, and then to bring them into conformity with the die before age-hardening takes place. This can be readily done by the press or drop hammer, but it is rather difficult to do by hand. Another reason is that bumped parts are not efficient structurally, as a curved surface is weak in compression.

184. Annealing Bumped Metal.—Annealing can be done very readily by using an oxyacetylene torch with acetylene only. Thoroughly soot the surface of the material, then neutralize the flame, and *just burn off the soot.* Great care must be taken not to overheat the metal in the process, or damage will result.

Burning off the soot gives the correct temperatures. The metal should then be allowed to cool in air.

In press and drop-hammer work it is usually not necessary to anneal the metal.

185. Bending Sheet Metal.—Bend blocks are made up of metal or of maple. They must be guided in place with steel dowel pins to insure conformity. Small blocks are used in the vise, but the larger blocks require a hydraulic press.

Extruded sections work well in the bend blocks, but rolled or drawn sections may also be formed in them. It is excellent practice to make up suitable bend blocks for every minor forming operation, just as it is best to make dies for bumping. In fact, the processes of forming and bumping are quite similar.

Review Questions

1. Make a list of the equipment required in a sheet-metal shop.
2. Why is grinding of aluminum alloys difficult?
3. What is meant by "metal bumping"?
4. Explain how a bumping die can be made of cement.
5. Explain the process in hand bumping.
6. Explain how a die for power bumping is made.
7. How are rubber pads used in forming thin sheet metals?
8. What aluminum alloys are most suitable for bumping and why?
9. Why is bumping not used for structural parts?
10. Explain how to anneal bumped aluminum alloys.

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1. WELCH, R. L., "Elements of Sheet Metal Work," The Bruce Printing Company, Milwaukee, Wis.

2. VAN LEUVEN, E. P., "Cold Metal Working," McGraw-Hill Book Company, Inc., New York, 1931.

3. LONGFIELD, E. M., "Sheet Metal Drafting," McGraw-Hill Book Company, Inc., New York, 1921.

4. BROEMEL, L., "Sheet Metal Workers Manual," F. J. Drake and Co., Chicago, 1936.

Question for Thought and Study of References

1. Describe a squaring shear and its use.
2. Describe the use and operation of beading rolls.
3. How is a bend block used in forming thin sheets of metal?
4. What aluminum alloys are best for forming cowlings?
5. Why is bumping not used in forming structural parts?
6. Describe the process of metal spinning.
7. Name some airplane parts formed by spinning.
8. What is annealing?
9. Why should fairing which requires excessive forming be made of aluminum?

CHAPTER XI

RIVETS AND RIVETING

In the repair of aluminum-alloy structures, riveting is an essential requirement. Let us bear in mind, however, that the usual sheet-metal riveting, while it may be good, is not good enough for aircraft riveting. Riveting in aircraft structures is done with strength as the primary requirement.

186. Types of Riveted Joints.—The principal types are:

1. Lap joint, Fig. 153*a*.
2. Butt joint, Fig. 153*b*.

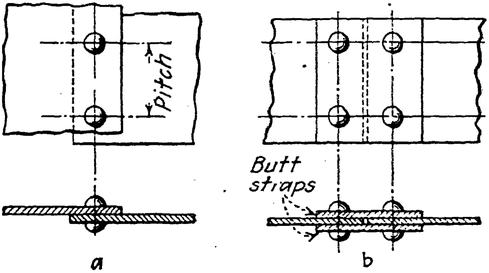

FIG. 153.—Kinds of riveted joints.

Either of these types of joints may have one, two, or more rows of rivets.

The center-to-center distance between the rivets in a row is called the *pitch*.

If two rows of rivets are used, the rivets are usually *staggered;* that is, the rivets in the rear row are not placed directly behind those in the front row but are placed halfway between those of the front row.

187. Types of Rivets.—Figure 154 shows the usual types of rivets. They are:

1. *Buttonhead.*—This is used in thick sheets where strength is required.
2. *Roundhead.*—Used same as (1), but the head covers more area, making it more adaptable to thin sheets.

3. *Mushroom Head.*—Used same as (2), in the air stream, since it offers less resistance.

4. *Brazier Head.*—Used in air stream and for thin sheets.

5. *Flathead.*—Used for inside riveting where a flathead is required.

6. *Countersunk.*—Used for riveting wherever the finished job must be smooth and flush.

7. *Oval Countersunk Head.*—Used as (1), where a larger head area is necessary.

8. *Tubular Shank.*—Used for special riveting jobs. See also Thomson rivets in Par. 188.

Four types of rivets are used for 90 per cent of all the aeronautical work, roundhead, brazier head, flathead, and countersunk or flush. The brazier head and countersunk are used on the outside exposed surfaces, the latter being overwhelmingly used on about the front third of the wings, fuselages, and tail surfaces, but many designs are flush-riveted all over.

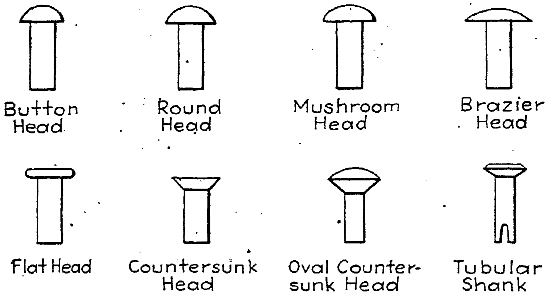

FIG. 154.—Types of rivets.

Rivets are made of as many alloys as are the sheets and extrusions to be fastened. Actually, only four alloys are used for practically all applications. Two of these, A17S and 2S, need no heat treatment followed by cold storage (to delay hardening). 24S and 17S are used for the high-strength parts that must be heat-treated to the maximum strength.

It is relatively simple to tell the various alloy rivets apart. The two nonheat-treated rivets, 2S and A17S (the first sometimes called a *soft* rivet and the latter an *A* rivet) have a plain and a dimpled head, respectively. The heat-treatable rivets, 17S and 24S, have a raised dot on the former and two raised dashes on the head of the latter. After driving, the dimple is still apparent in the A rivet and usually the dot and dashes are still visible in the 17S and 24S rivets, but not always.

Countersunk or Flush Riveting.—As mentioned elsewhere, most modern airplanes are flush-riveted over the front third of all outside surfaces. This is done because even small irregularities near the entering or leading part of a body increase the drag of that body to a marked degree by the increased turbulence they cause. Back of the forward part, small irregularities are of less moment, for they will then be within a layer of turbulent air whose thickness increases the farther the air travels over the body. Even so, however, there is something to be gained by using flush rivets throughout, and some airplanes are thus built.

Flush rivets represent a problem in repair. It is not good practice to replace them with rivets of other types. Flush rivets, ordinarily, have two types of head, 78 and 100 deg., the former for the thicker plates. The trick in flush riveting is in forming the countersink or dimple for the cone-shaped head. If the cover sheet is thick enough, this is simply done by counterboring the rivet hole to the proper depth with a properly shaped counterbore bit, guarded so as not to cut too deeply.

More commonly, however, the cover sheet, and often the stiffener, undersheet, or other part being riveted will be too thin. Sometimes, use of the 100 deg. head will help, as the depth of counterbore is less for this type. Ordinarily it will be necessary to "coin" the countersink into the parts or, in some cases, to "spin" it in. Either, if carefully done, will be satisfactory. In each case, an undersized hole is drilled first. Next, the die and punch are applied with pressure or with blows to form the dimple, and then the hole is reamed out with the proper-sized drill for the rivet. Spinning takes more skill and is not recommended. *The important thing is for the dimple to be formed without damaging the parts to be riveted.*

188. Thomson Rivets.[1]—Thomson rivets are characterized by a depression in the shank (see Fig. 155). The depression is still visible after the head is formed, but then it is only a shallow dimple. In driving a Thomson rivet the working of the metal is confined largely to the region of the depression. Hence the shank does not expand as much as in a solid rivet. As a result the

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[1] "Maintenance Instruction," The Curtiss Aeroplane and Motor Company.

Thomson rivet should fill the hole closely before driving. If not, a solid rivet is better.

There are three methods of installing and setting Thomson rivets, namely, by *machine*, by *squeezers*, and by *hand tools.*

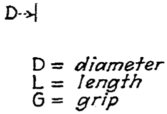

FIG. 155.—Thomson tubular rivet.

The Thomson rivet machine consists of a hopper, a gravity feed chute with a device allowing only one rivet to fall at a time, a set with receding pin for locating work and guiding rivet through hole, and a mechanically actuated plunger which heads the rivet. The use of the machine is limited to riveting small assemblies and such parts as may be easily maneuvered by hand.

TABLE XVII.—THOMSON RIVETS* 670-D

1/8-in. diameter		3/16-in. diameter	
Stock thickness	Length	Stock thickness	Length
0.0 to 0.027	3/32	0.063 to 0.095	3/16
0.028 to 0.059	1/8	0.096 to 0.125	7/32
0.060 to 0.090	5/32	0.128 to 0.156	1/4
0.091 to 0.121	3/16	0.157 to 0.188	9/32
0.122 to 0.152	7/32	0.189 to 0.218	5/16
0.153 to 0.184	1/4	0.212 to 0.250	11/32
0.185 to 0.215	9/32	0.251 to 0.281	3/8
0.216 to 0.247	5/16	0.282 to 0.313	13/32
0.248 to 0.278	11/32	0.314 to 0.344	7/16
0.279 to 0.309	3/8	0.345 to 0.375	15/32
0.310 to 0.340	13/32	0.376 to 0.408	1/2
0.341 to 0.372	7/16	0.407 to 0.438	17/32
0.373 to 0.403	15/32	0.439 to 0.469	9/16
0.404 to 0.434	1/2	0.470 to 0.500	19/32
		0.501 to 0.531	5/8
		0.532 to 0.562	21/32
		0.563 to 0.594	11/16
		0.595 to 0.625	23/32
		0.626 to 0.656	3/4

* Courtesy of Curtiss Aeroplane and Motor Company.

In squeezing Thomson rivets either hand or pneumatic squeezers are used. The jaws of each type are equipped with removable sets of size and shape to suit the different rivet sizes. In each case one set is shaped to fit the manufactured head and one to fit the formed head. Squeezers are used for riveting large assemblies such as monocoques, panels, and parts which may not readily be riveted on a machine.

Where rivets are so inaccessible that they cannot be set with machine or squeezer, hand tools and hammer are used.

This method is probably the most common in replacing rivets. Rivets may be driven from either side, depending upon which is more convenient.

In replacing a rivet which has been removed, drill the hole out and use the next larger size Thomson rivet, except in cases where the net section is critical. In such cases the same size Thomson rivet may be used if the hole is not oversize. If the hole is oversize, it will be found better to use the same size solid rivet. For ⅛-in.-diameter rivet, drill No. 30 (0.128) diameter hole; and for $3/16$ in. diameter, drill $3/16$-in.-diameter hole. When a rivet is formed, the bottom of the hole in the end can be below the outermost surface of the material on the side of the formed head not over 0.032 on ⅛-in. rivet and not over 0.040 on $3/16$-in. rivet.

Dural Thomson rivets must be driven with a small amount of linseed oil or paint on Navy jobs to get a well-formed head. Care should be taken to have sheets tight together, or rivet will collapse between sheets. Dural rivets require special sets, both for machine and hand driving. Dural rivets should be $1/32$ in. longer than those called for on chart for steel.

Table XVII shows the correct lengths of rivets to use for various stock thicknesses.

189. How a Riveted Joint May Fail.—Figure 156 shows several types of failure of a riveted joint. They may be listed as follows:

1. Shear of the rivet.
2. Shear in the plate.
3. Tearing of the plate by compression.
4. Crushing the rivet.
5. The rivet head may pull off.

An ideal joint is one which will be of equal strength in all of these characteristics.

An inspection of a riveted joint should include a check of the joint for all possible types of failure.

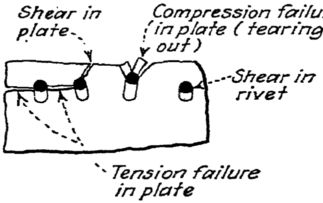

Fig. 156.—Types of failures riveted joint.

190. Heat Treatment of Aluminum-alloy Rivets.—Rivets of 2S and 3S do not need heat treating before driving, although they do *work-harden* in driving. This is a desirable feature to prevent permanent deformation under load and loosening as a result. It is imperative that 17S rivets be heat-treated before driving, as they are too hard normally and, if driven untreated, are very apt to split around the edge of the head. *The hard rivet will also swell the hole in the sheet, causing it to wave between rivets.*

The heat treatment of duralumin rivets is a comparatively simple operation, but the temperature must be properly controlled to obtain satisfactory results. Although there are several types of furnaces used for the treatment of rivets and small duralumin parts, the salt-tank type is the most widely used. This consists of a steel tank of sufficient capacity to handle the desired volume of work, with some means of heating (electricity, gas, etc.). The salt bath, which is a half-and-half mixture of pure sodium nitrate and potassium nitrate, is heated to from 940 to 960°F. in the heat-treatment process, and is maintained at this temperature through the use of a *pyrometer.* The rivets are left in the solution 10 to 20 min., depending upon the size of the rivets. After the rivets have been in the salt bath for the required period, they should be taken out and quenched in cold water and then washed off. Two tanks should be used for the quenching and washing operations.

The rivets should be driven within one half hour after quenching; otherwise they will become excessively hard, and retreatment will be necessary.

After they have been quenched, the rivets are soft, but they start aging immediately, obtaining their maximum hardness in about four days. This feature is very advantageous, as it allows sufficient time for the job to be finished before the maximum hardness is developed. If, for any reason, it is desired to keep the rivets soft after heat treatment, they may be placed in an atmosphere below 32°F., as in containers surrounded by dry ice (solid carbon dioxide). In this way the rivets may be kept soft enough for driving for several hours.

Practices to Be Avoided.[1]—There are certain practices which we have observed in contacting the industry, which we feel should be carefully avoided. As examples of such practices, we are listing the following:

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[1] "Report on Recommended Practices," by Aluminum Company of America.

1. Quenching 17S or 24S alloys in hot water or air after heat treatment. This procedure not only affects the mechanical properties of the resulting material, but has a very serious effect upon its resistance to corrosion.
2. Insufficiently rapid transfer of 17S or 24S alloys from the heat-treating medium to the quench tank. This transfer should, at least for small loads, be accomplished in the very minimum of time. An elapsed time of more than 10 or 15 sec. will, in many cases, result in a lowered rivet strength.

191. Riveting of Stainless-steel Sheets.—Riveting of stainless steel is done either hot or cold. Small rivets may be drawn cold and set by comparatively few heavy blows. Hot rivets should be heated out of contact with the furnace flame or in electric resistance heaters, which use the rivet as the circuit between two electrodes of low electrical resistance, to a temperature of 2100°F. These hot rivets must be set so that mechanical deformation is finished before they cool to below 1750°F. Riveting is of doubtful economy in structural joints. The holes are readily torn. Stainless rivets harden rapidly and are difficult to handle.

192. Strength of a Riveted Joint.—A riveted joint can never be as strong as the uninterrupted sheet; that is, its strength can never be 100 per cent. For example, if the pitch of the rivets is 1 in., and the diameter of the rivets is ⅛ in., then ⅛ in. of metal is cut from a strip 1 in. wide, leaving the strip only ⅞ in. wide. The strength then is (⅞ ÷ 1 × 100 per cent), which is 87.5 per cent of that of the undrilled sheet.

As generally required in aircraft work, the strength of the plate and the strength of rivet must be about the same. For example, it would not be good practice to use a ¼-in. rivet in a 0.020-in. sheet; nor would it be good practice to use a 1/16-in. rivet in a ¼-in. plate.

Tables XVIII, XIX, and XX will prove convenient and useful to the mechanic in making repairs. The tables show the rivet strengths, the strength of the plate for the different-sized rivets, and the values to use to give equal strength of plate and rivet.

Note that the shearing strength is taken as 25,000 lb. per square inch in Table XVIII. This is a conservative value for general use, as the higher strength aluminum-alloy rivets develop 30,000 to 40,000 lb. per square inch shear strength. It is best to be on the safe side.

TABLE XVIII.—A17ST, RIVETS—SHEAR AND BEARING VALUES*
NOTE: The use of rivets in tension is to be avoided.

Size	3/32	1/8	5/32	3/16	7/32	1/4	5/16
Area of shank, sq. in.	0.00690	0.0123	0.0192	0.0276	0.0376	0.0491	0.0767
Single shear 25,000 lb. per sq. in.	172	308	480	690	940	1228	1918
Double shear	344	616	960	1380	1880	2456	3836
Sheet thickness	Bearing strength, lb. (60,000 lb. per sq. in.)						
0.014	78	105	131	157	184	210	262
0.016	90	120	150	180	210	240	300
0.018	102	135	169	202	236	270	337
0.020	113	150	187	225	262	300	375
0.022	124	165	206	247	289	330	413
0.025	141	187	234	281	328	375	468
0.028	158	210	262	315	367	420	525
0.032	180	240	300	360	420	480	600
0.036	202	270	337	405	473	540	675
0.040	225	300	375	450	525	600	750
0.045	253	337	422	506	590	675	845
0.051	287	382	478	574	670	765	955
0.057	321	427	535	641	747	855	1070
0.064	360	480	600	720	840	960	1200
0.072	405	540	675	810	945	1080	1350
0.081	456	607	760	910	1060	1215	1520
0.091	512	682	855	1025	1192	1365	1705
0.114	642	855	1070	1280	1495	1710	2140
0.128	720	960	1200	1440	1680	1920	2400
0.156 (5/32)	877	1170	1460	1755	2049	2340	2930
0.188 (3/16)	1054	1405	1760	2120	2460	2820	3520

* Courtesy of Douglas Aircraft Company.

NOTE: Values below upper solid line are greater than single shear.
Values below lower solid line are greater than double shear.

CAUTION: The A17 rivets are used where the loads are not too severe. These rivets are *not* heat-treated before driving and must be protected by dipping in a dichromate solution as they cause corrosion in the sheet, particularly the 24 alloy. The dichromate leaves a yellow stain.

See Job Unit 26, 27, etc., for examples of the use of Tables XVIII, XIX, and XX.

TABLE XIX.—BEARING STRENGTH OF ALUMINUM-COATED ALUMINUM-ALLOY SHEET—24S ALCLAD (SPEC. 11067)*

Diameter of rivet or pin, in.	1/16	3/32	1/8	5/32	3/16	1/4	5/16
Single shear strength, lb.	107	242	430	671	966	1717	2684
Sheet thickness, in.	Bearing strength of sheet, lb.						
0.012	61	91	122	152	183	244	305
0.016	82	123	164	205	246	328	410
0.020	**102**	153	204	255	306	408	510
0.025	128	192	256	320	384	512	640
0.030	154	**231**	308	385	462	616	770
0.035	179	268	358	447	537	716	895
0.040	205	307	**410**	512	615	820	1025
0.045	231	346	462	577	693	924	1155
0.051	261	391	522	**652**	783	1044	1305
0.057	292	438	584	730	**876**	1168	1460
0.064	328	492	656	820	984	1312	1640
0.072	369	553	738	922	1107	1476	1845
0.081	415	622	830	1037	1245	**1660**	2075
0.091	466	699	932	1165	1398	1864	2330
0.102	523	784	1046	1307	1569	2092	**2615**
0.128	656	984	1312	1640	1968	2624	3280
0.156	799	1198	1598	1997	2397	3196	3995
3/16	961	1441	1922	2402	2883	3844	4805
1/4	1281	1921	2562	3202	3843	5125	6405

* Courtesy of U. S. Army Air Corps.

All values appearing below figures in bold-face type in each column are greater than single shear.

Allowable bearing = 82,000 lb. per square inch. Allowable shear—24S (Spec. 11071) rivet = 35,000 lb. per square inch.

193. Types of Riveting.—The types of riveting may be classified as follows:

1. Hand peening.
2. Automatic hammer riveting.
   a. Electric hammer.
   b. Air hammer (air gun). See Fig. 162.
   c. Mechanical hammer.
3. Squeezing rivets in place.

a. Hydraulic power.
b. Air power.
c. Mechanical power.

Very little hand peening is done in aircraft work. There are various sizes of automatic hammers to fit the various sizes of rivets. The hammer is usually applied to the head of the rivet with the rivet in position through a block, stationary with respect to the rivet but attached to the hammer, while the dolly bar forms the cap on the shank end of the rivet. This practice makes riveting possible in places which would otherwise be inaccessible.

Table XX.—Bearing Strength of Aluminum-alloy Sheet-17S (Spec. *QQ-A*-353)*

Diameter of rivet or pin, in.	1/16	3/23	1/8	5/32	3/16	1/4	5/16
Single shear	92	207	368	575	828	1472	2300
Sheet, thickness, in.	Bearing strength of sheet, lb.						
0.012	56	84	112	140	168	224	280
0.016	**75**	112	150	187	225	300	374
0.020	94	141	187	234	281	375	469
0.025	117	**176**	234	293	351	468	586
0.030	141	211	281	352	422	562	704
0.035	164	246	**328**	410	492	656	820
0.040	188	281	376	469	563	750	938
0.045	211	316	422	**527**	633	844	1054
0.051	239	359	478	598	717	956	1196
0.057	267	401	534	668	**801**	1068	1336
0.064	300	450	600	750	900	1200	1500
0.072	338	506	676	844	1014	**1352**	1688
0.081	380	570	760	950	1140	1520	1900
0.091	427	640	854	1067	1281	1708	**2134**
0.102	478	717	956	1195	1434	1912	2390
0.128	600	900	1200	1500	1800	2400	3000
0.156	731	1097	1462	1828	2193	2924	3656
3/16	879	1319	1758	2198	2637	3516	4395
1/4	1172	1758	2344	2930	3516	4688	5860

* Courtesy of U. S. Army Air Forces.

All values appearing below figures in bold-face type in each column are greater than single shear.

Allowable bearing = 68,000 lb. per square inch. Allowable shear—17S (Spec. *QQ*-A-351) rivet = 30,000 lb. per square inch.

The riveting is usually done by the dolly bar or dolly block. The rivet set or "snap" is held in the "gun" and usually has a shape conforming to the size and shape of the rivet head. Often a piece of scotch tape will be over the rivet head to take up minor inequalities and to reduce "ringing" of the plate or of the rivet. The rivet set must be straight upon the rivet, with the rivet head in contact with the surface of the material to be riveted. The "bucker" must hold the dolly bar normal to the end of the rivet shank and, as the blows are struck, the impact of the rivet against the dolly flattens the end of the shank and swells it to fill the rivet hole. It takes more skill to do a good job of bucking than it does to handle the hammer. The bucked end of the rivet should be flattened to 0.40 to 0.65 of the nominal rivet diameter, and the head thus formed to about $1\frac{1}{3}$ to $1\frac{1}{2}$ times the rivet diameter.

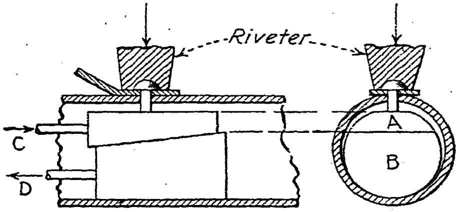


FIG. 157.—Riveting to the walls of a tube.

Dolly bars and blocks are of many sizes and shapes to allow bucking in close corners and in confined places. They can be improved readily as the primary needs are a smooth bucking surface and sufficient inertia (weight) to head up the rivet. Modern riveting makes little attempt to make other than flat heads on the bucked end of the rivets, but sometimes a round or brazier head is desired, when the dolly must have a depression of the proper size to make it.

The squeeze-type riveter is quite generally used in connection with very accessible work, such as in riveting small parts which may be readily moved. This type of riveting is quite rapid and generally satisfactory.

194. Riveting in Small-diameter Tube.—The strength efficiency of a tube in thin-sheet-metal construction, especially where torsion is involved, outweighs the inefficiency of fabrication. Figure 157 shows the most common method of bucking rivets inside a tube. The steel blocks *A* and *B* slide on each other at the inclined surfaces when actuated by the rods *C* and *D*, extending out of the end of the tube. This sliding action causes the shank to decrease as the cap is formed on the rivet. A device of this kind may be pneumatically or hydraulically actuated, also. It is usually called a mouse.

While there are many other devices for this purpose, it is sufficient for the designer to realize the possibilities, so that he may not be handicapped in his design.

195. Rules for Riveting.—The following general rules should be adhered to:

1. Tension on rivet heads should be avoided. Figure 158 shows how a single riveted lap joint in thin sheets may develop tension. A butt joint would be more desirable in this case.

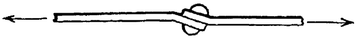


FIG. 158.—Tension on rivet heads in lap joint.

2. A riveted seam in thin material should be backed up by an angle section, or equivalent, as shown in Fig. 159.

3. In general, the rivets should be regularly and equally spaced.

4. If the riveting is done in double rows, the rivets of the two rows should be staggered.

5. Where butt straps are used (in a butt joint, Fig. 153*b*), the straps should not be of less thickness than the plate.

6. The thickness of the plate should regulate the size of the rivet (see Tables XVIII, XIX, and XX).

7. The rivet holes should have smooth and regular sides, without burrs or cracks. A drilled hole is best.

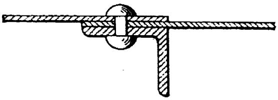


FIG. 159.—Reinforcing a seam-riveted joint.

8. Rivets should be dipped into a good quality of bituminous paint before inserting to retard corrosive effects.

9. The sheets should be bolted together with small bolts, which fit the rivet holes, while the remaining holes are being drilled and while rivets are being driven.

10. In general, rivets should not be nearer to butts or edges of the plating, straps, or bars than a space equal to one and one-half times the diameter of the rivet.

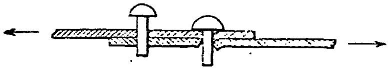
11. In general, in edge riveting, the space between any two consecutive rows of rivets should not be less than two rivet diameters.

12. The rivet holes should not be too small. Figure 160*a* shows the effect of this poor practice. As noted, the sheet is bent, giving a poor bearing area.

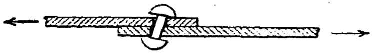
13. The rivet holes should not be too large. The sheets slip in this case, as shown in Fig. 160*b*, developing a tendency to pull the head off the rivet.

Also, as noted in Fig. 160*c*, the rivet in the large hole may not carry its load, leaving the additional rivet to carry the entire load. Since the joint is designed for two rivets, one rivet must carry the load of two, which load shears the rivet off.

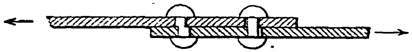
14. The rivet must not be too long or too short. If the rivet is too long, it tends to bend, thus buckling and mutilating the plate, as noted in Fig. 160*d*. If the rivet is too short, the head cannot be made large enough, as shown in Fig. 160*e*.



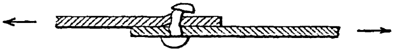
(*a*) Holes Drilled too Small



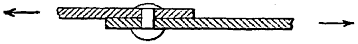
(*b*) Hole Drilled too Large



(*c*) One Hole Drilled too Large



(*d*) Rivet too Long



(*e*) Rivet too Short

Fig. 160.—Poor practices in riveting.

15. A prick punch should be used in laying out the holes to be drilled. An automatic prick punch is more desirable. (See a tool catalogue for prick punches and center punches.)

16. A sharp point should not be used in laying out lines for rivets, as the point will cut the sheet, making it susceptible to fatigue stresses.

17. Dividers are used for laying out the distances between holes.

18. A rivet set is used in setting rivets. (See tool catalogue.)

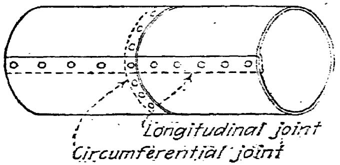


Fig. 161.—Riveted joints in a tube.

196. Heading Rivets in Repair Work.[1]—If the rivets have been removed carefully, the same-size rivet as used originally can be replaced in the holes. The shank of the rivet should project out a distance equal to about one and one-half or two times its diameter. In the factory, the large assortment of rivets makes it possible always to have the proper length on hand. In the field, however, it will usually be necessary to use long rivets and cut off the shank to the required length with a pair of cutting pliers or small tin shears. The rivet is normally put in and bucked from the inside so that the head is formed on the outside, and it is well to daub the hole with Bakelite seam compound to prevent leakage and corrosion. Until experience has been gained, the rivet should not be set too tight. A loose rivet can be tightened, but too much hammering may injure the sheets, causing dents and tending to expand the metal so that it bulges out between rivets.

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[1] Recommended in "Service Manual," Edo Aircraft Corporation.

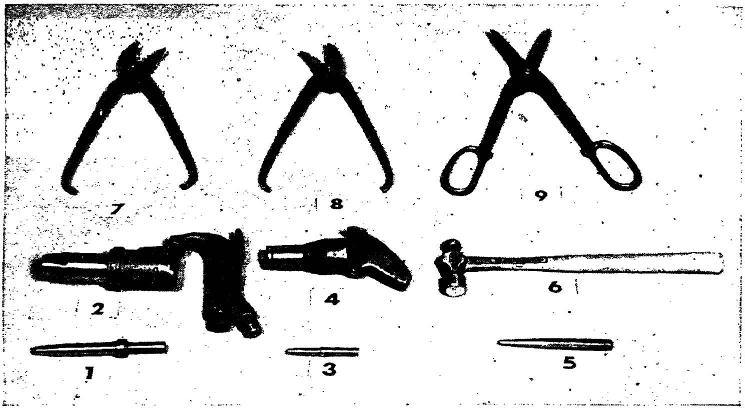

FIG. 162.—(1) Rivet snap for heavy gun; (2) heavy air gun (used for duralumin rivets up to ¼ in. diameter); (3) rivet snap for light gun; (4) light air gun (used for duralumin rivets); (5) hand snap; (6) machinists ball peen hammer for head riveting; (7) left-hand "Dutch" snips; (8) right-hand "Dutch" snips; (9) straight-away snips. (*Courtesy of Boeing School of Aeronautics.*)

There are two essentials in properly heading rivets. In the first place, the bucking bar must be really pressed and held tightly against the rivet. It is sometimes difficult to see whether the bucking bar is up tight, and in such case the man on the outside should check it by trying to push the rivet in before he starts putting a head on it. *In the second place, the sheets of metal which are being* *riveted must be drawn tightly together before riveting is started.* This can be accomplished by the free use of machine screws in preliminarily clamping the sheets together.

If many rivets are to be put in, a special *draw set* can be used to advantage. This is essentially a rod with a hole drilled in one end to a size $\frac{1}{32}$ in. larger than the shank of the rivet and short enough to expand the head of the rivet at the same time that it draws the metal together. After the rivet has been placed in the hole and bucked, a few blows are given with this tool before driving it. *If the rivet is properly driven and the sheets drawn together, a watertight joint is assured.* If the sheets are not drawn together, the shank of the rivet will expand between the sheets, and although the rivets may look all right from the outside, water will leak in between the sheets.

It is advisable to use a rivet set to put the head on the shank of the rivet, and it is important to hold it parallel with the shank, or else a defective head will be formed. Eight or nine blows with a medium-weight hammer on the set should be sufficient to form a good head. There are a few awkward places in the float where it is very difficult to insert a rivet from the inside. In these cases, insert a wire through the hole in the float from the outside. This wire can be fastened to the rivet by filing a point on the rivet and drilling a hole through the narrow part. The point of the rivet is then drawn through the hole by pulling on the wire. Do not unfasten the wire until sure that the rivet is properly bucked from the inside.

Where compressed air from 80 to 150 lb. pressure is available, a type "U" Boyer compressed-air scaling hammer, which can be obtained from the Chicago Pneumatic Tool Company, will drive rivets in about half the time required by hand. In this case, the rivet is pushed into the hole from the outside and the hammering is done against the head of the rivet. The pushing up of the bucking bar against the shank of the rivet forms a head on the inside. This type of hammer requires care in handling and is not recommended unless extensive rebuilding work is to be accomplished.

197. Parker-Kalon Screws.—These screws are often quite valuable in repairs. Any aircraft supply house can supply information on them, otherwise write to the manufacturer. The following outline describes their use and application:

The screws are made of very hard steel, and are designed so that they tap their own threads in the softer aluminum alloy. When the hole is drilled the proper size, the screws will fit quite tightly, thus offering a high resistance to unscrewing. They may be obtained chromium-plated, in stainless steel, or in other forms.

2. The screws are useful in joining metal sheets in such a position that no access is available for bucking rivets; for example, in attaching a covering to a frame of a closed cylinder.

3. See Job Unit 42 for example of use of the screws in repair.

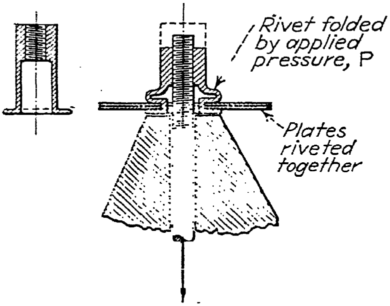

FIG. 163*a*.—Method of heading Goodrich Rivnuts.

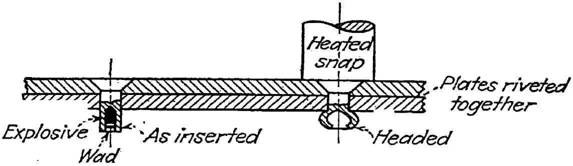

FIG. 163*b*.—Explosive rivet.

198. Blind Riveting.—Blind riveting is used where the rivet cannot be reached for heading with a bucking bar. One type is known as the Goodrich Rivnut. Its use for blind riveting has become quite general (see Fig. 163*a*). The rivet is hollow and the end opposite the head has an internal thread for approximately half the length. The remaining length is counterbored to a somewhat larger diameter than the thread. The rivet is headed by means of a tool with a threaded mandrel which is screwed into the threaded portion of the rivet. The tool bears against the head of the rivet (Fig. 163*a*) and withdraws the mandrel, which upsets the counterbored portion, as shown in the figure. The rivets and heading tools are made in a countersunk pattern, as well, which may be obtained from the B. F. Goodrich Co.

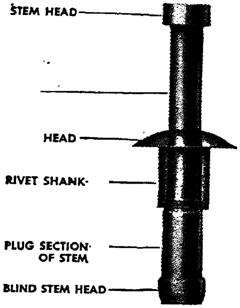

FIG. 163*c*.—The Cherry rivet.

The *explosive rivet* is a very useful one for blind riveting. The rivet is of any normal type, except that the end of the shank is drilled out a short distance and the hole is packed with a small amount of a special explosive, held in place with a wad.

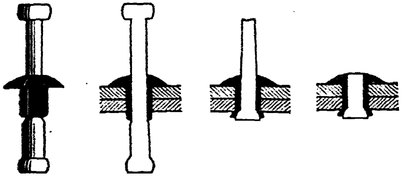

Fig. 163*d*.

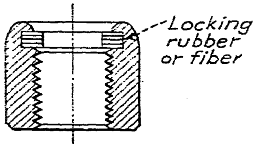

Fig. 164.

Fig. 163*d*.—Mandrel in the self-plugging Cherry rivet, when pulled by special gun, forms tulip head, expands rivet shank, permanently plugs rivet, and then breaks, releasing gun. The mandrel is then trimmed.

Fig. 164.—Standard Elastic Stop Nut.

The rivet is put in place and a heavy, heated, properly shaped set is held against it. The heating of the rivet resulting therefrom sets off the explosive. The consequent explosion expands the shank to form a head (see Fig. 163*b*) on the blind end.

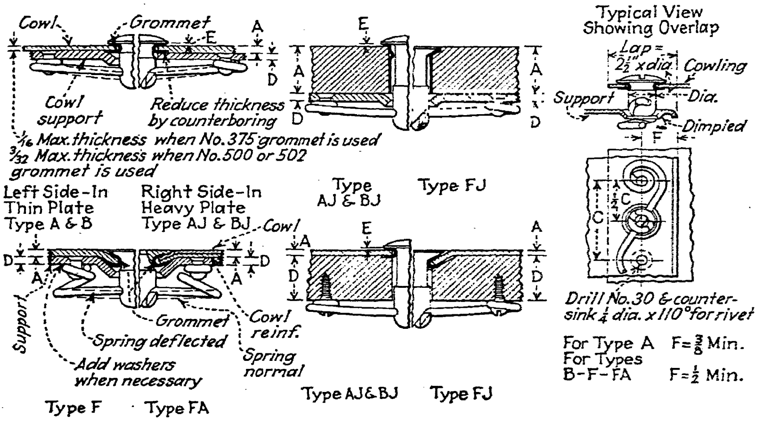
Cowl
Grommet
E
A
D
Cowl support
Reduce thickness by counterboring
1/16 Max. thickness when No.375 grommet is used
3/32 Max. thickness when No.500 or 502 grommet is used
Left Side-In Thin Plate Type A & B
Right Side-In Heavy Plate Type AJ & BJ
Type AJ & BJ
Type FJ
Typical View Showing Overlap
Lap = 2½" x dia.
Cowling
Support
Dia.
Dimpled
F
C
½C
Drill No.30 & countersink ¼ dia. x 110° for rivet
For Type A F = ⅜ Min.
For Types B-F-FA F = ½ Min.
Cowl
Support
Grommet
Cowl reinf.
Spring deflected
Spring normal
Add washers when necessary
Type F
Type FA
Type AJ & BJ
Type FJ

Fig. 165*a*.—Typical Dzus fasteners for aircraft. (*Courtesy of Dzus Fastener Co.*)

This rivet can be used in the most confined spaces and is quite satisfactory.

The *Cherry rivet* is the most universally used type of blind rivet. Figure 163*c* shows the construction of the unheaded rivet and the nomenclature for the various parts. Figure 163*d* shows four stages of its application. The rivet is a standard aircraft rivet drilled for a special mandrel illustrated in Figs. 163*c* and 163*d*, referred to. A special gun that is made for either hand or air operation is used. The rivet is patented and made by the Cherry Rivet Company, from whom full information can be secured.

199. Elastic Stop Nuts (see Fig. 164).—The self-locking nut which bears the trade name Elastic Stop Nut has to a large extent supplanted the castellated nut and cotter key for bolted assemblies. Its use is disapproved where the parts joined rotate with respect to each other and where it is subjected to elevated temperatures but, beyond these applications, its use is practically unrestricted.

200. Cowl Fasteners (see Fig. 165*a*).—These fasteners are used for holding inspection covers, cowls, etc., in place. The fastener, which is locked by a spring as noted in the figure, is operated by a screw driver. The head of the screw is oval or countersunk, so that a smooth, streamlined surface is maintained.

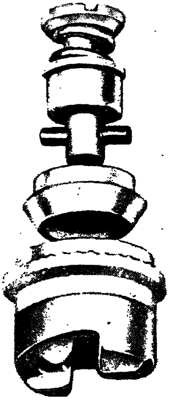

FIG. 165*b*.—Camloe rivet.

Another type of fastener that has merit, in that only one hole is needed for installation, is known as the Camloe. It is shown in Fig. 165*b*.

JOB UNITS

Job Unit 22. Making Lap-riveted Joint

A. Processes and Operations

1. Laying out.
2. Prick-punching.
3. Drilling.
4. Riveting.

B. Tools and Materials

1. Small electric or air riveting hammer.
2. Dividers.
3. Scale.
4. Prick punch.
5. Small hard drill.
6. Rivet set.
7. Pencil for layout.
8. Two plates 3 by 6 in. of 0.051 A17ST aluminum alloy.
9. Aluminum-alloy rivets.

C. Procedure

1. Select proper size of rivets from Table XVIII for equal strength (approximately) of sheet and rivet (see Par. 192).
2. Heat-treat the rivets. See Par. 190.
3. Cut the rivets to the proper length, if the proper length of rivets was not in stock.
4. Estimate the distance from the edge of the plates the rivets should be placed. See Par. 195.
5. Estimate the pitch so that the joint will be about equal in shear strength and in tension. If this gives the pitch less than ½ in., make the pitch ½ in.
6. Lay out the rivet holes along the 3-in. edge of the plates. Divide the width so that the rivets are equally spaced, and sufficient space is left between the last rivets in the row and the sides of the plate.
7. Prick-punch or center-punch the holes, and drill to size so that the rivets will fit smoothly without forcing. Drill first end hole through both plates; insert bolt to fit, then drill the other end hole through both plates, and insert bolt to fit. Now drill remaining holes (through both plates, of course).
8. Insert rivet in center hole and fit snuggly in place with rivet set.
9. Head rivet.
10. Head rivets in the remaining free holes, then remove bolts and head rivets in end holes.

Job Unit 23. Making a Butt-riveted Joint

A. Processes and Operations.—Same as in lap joint. See Job Unit No. 22.

B. Tools and Materials.—Same as Job Unit 22, except that material for butt straps should be provided. See Par. 195.

C. Procedure.—Same as Job Unit 22, except that the student should determine the thickness and size of the butt straps, and then cut them to size.

Job Unit 24. Testing Riveted Joints for Strength

Object.—To determine by test the actual strength of a riveted joint prepared by the student.

Tools and Materials

1. A tension-testing machine. (If a standard machine is not available, a jig and a loading platform may be easily devised so that the load may be applied by sand bags.)
2. Test the joint, noting the breaking load, and the types of failure in the joint.
3. Compute the strength of each rivet in single shear.

NOTE: The butt-joint test will give a more accurate value, since the lap joint will develop tension in the rivets. In the butt joint the rivets are in double shear. As an example, suppose there are six rivets on each side of the joint. This means 12 single shear values. Suppose the total load is 3,696 lb., then the single shear value for each rivet is 3,696 divided by 12, which is 308 lb. per rivet.

4. The shear value will probably be greater than the values given in Table XVIII if the rivets are well heat-treated and the joints are well made. The load must be applied evenly or progressive failure will result.

Job Unit 25. Other Job Units

1. Compare a joint made with rivets not heat-treated, with one made of heat-treated rivets.
2. Make joints of double rows of rivets and test.
3. Apply eccentric loading to riveted joints and note how progressive failure of rivets lowers the strength of the joint excessively.
4. Demonstrate the effect of having half of the holes too large.

Review Questions

1. Name and give an illustration of the types of joints.
2. Name five types of rivet-driving machines.
3. What size of A17ST rivet should be used in a 0.045-in. A17ST plate to give about equal rivet and plate strength?
4. Why cannot a riveted joint be made 100 per cent efficient?
5. Name and sketch the usual types of rivets.
6. State 10 rules for riveting.
7. How are rivets heat-treated?
8. How can the aging of rivets be retarded?
9. Explain the steps in making a riveted joint.
10. What are Parker-Kalon screws and how are they used?

References

1. "The Riveting of Aluminum," Aluminum Company of America, Pittsburgh, Pa.

2. YOUNGER, J. E., "The Mechanics of Aircraft Structures," McGraw-Hill Book Company, Inc., 1942. (Tables similar to Table XVIII for other materials may be found here.)

3. "Report on Recommended Practices for Construction and Repair of Aluminum Alloy Aircraft Structures," 1935, Aluminum Company of America, Pittsburgh, Pa.

Questions for Thought and Study of References

1. It is a simple matter to one familiar with solid geometry to calculate the exact length of a rivet to make a buttonhead on a rivet. If the head is taken as a hemisphere, then the volume of the rivet head must equal the volume of the rivet shank from which the head is to be made. Equate the formulas for the volume of a cylinder (rivet shank) and a hemisphere (rivet head) and solve for the length of cylinder required.
2. About how many rivets are there in a modern transport airplane?
3. Why are riveted joints instead of welded joints used in aluminum-alloy structures?

CHAPTER XII

REPAIR OF THIN-SHEET-METAL STRUCTURES

In general, any part of a metal airplane structure may be repaired and made as strong, or stronger, than the original part with the addition of only a small amount of weight. It is necessary, however, that the supervision of the repair work be under the direction of personnel who understands thoroughly the full requirements of repairs to metal structures.

201. Requirements to Be Met in the Repair of Metal Structures.—These are:

1. The strength of the original structure must be maintained.
2. The outside contour of the structure must be preserved.
3. Excessive weight should not be added in the repair.
4. Special consideration must be given to the corrosion resistance of the repair job.

202. General Types of Repair Jobs.—These may be classified as:

1. *Repairs of Highly Stressed Primary Members.*—These repairs pertain to the primary structural parts of the airplane, such as the wing spars, fuselage stringers, struts, etc. (see Par. 205 and Job Units 26, 27, 28, 29, 30, 31, 37, 38, and 39).
2. *Repairs of Highly Stressed Secondary Members.*—These repairs pertain to parts which are not designed to carry stresses but are stressed because of the distortion (elastically) of the airplane structure. Such parts of a structure as formers, the skin (in some cases), the engine cowling, etc., fall in this category. See Job Units 33, 39, 41, 42.
3. *Repair of nonstressed members,* such as fairings, fillets, and in some cases, engine cowling, and other aerodynamic surfaces. See Job Units 33, and 39.
4. *Repair of Surfaces Required to be Watertight, Gasolinetight, or Airtight.*—Such surfaces are float hulls for seaplanes, and gas and oil tanks. See Job Unit 42.

203. Minimum Equipment for Repair of Aluminum-alloy Thin-sheet Structure.—The following equipment, or equivalent, is necessary (see Fig. 162):

1. Electric drill with drills.
2. Tin shears.
3. Hacksaw.
4. Files.
5. Riveting hammer.
6. Wooden mallet.
7. Small cold chisel.
8. Rivet set.
9. Bucking bars.

If bumping or other forming is to be done, shop equipment, as noted in Chap. X, is also necessary.

In shops where compressed air is available, a small compressed-air automatic hammer is desirable. Riveting with such a hammer can be done in about half the time required by hand. *In using the air hammer, the rivet is pushed into the hole and the hammering is done against the head of the rivet.* The bucking bar pushed up against the shank forms the head on that end. The hammer, obviously, must be pushed against the rivet head with more force than the bucking bar is pushed against the shank. If the surface of the bucking bar is flat, it will, of course, make a flat head on the rivet. This is the usual practice.

204. Removing Rivets for Repairing.—Care must be taken in removing rivets for repairs, to avoid mutilating the sheet metal. Also, if rivets can be removed without marring the edges of the rivet holes, or without increasing the size of the rivet holes, the same holes and size of rivets may be used; otherwise the holes must be reamed out, and thus made larger. The following rules should be followed in removing rivets:

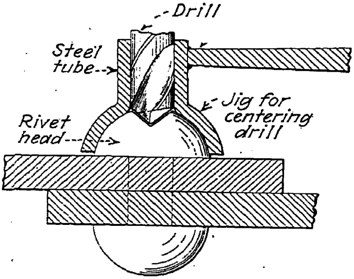

FIG. 166.—Jig for centering drill on rivet head.

1. *Center-punch the head of the rivet, and drill a hole in the head slightly smaller in diameter than the rivet shank is assumed to be.* Do not drill to the sheet metal, as it is quite difficult to drill in the center of the shank and the rivet hole in the sheet metal may be elongated.

   A jig for drilling rivet heads (Fig. 166) may be made of a small steel tube about 1 in. long, to which is welded a handle at a right angle to the tube axis. The tube should fit the drill, and should be cupped at one end to fit the rivet head.

2. *After the rivet head is weakened by drilling, knock the head off with a small sharp cold chisel by using a single smart blow with a hammer.* A series of light blows will only bend the rivet and tear the sheet. The chisel should have a face about ⅜ in. wide, set at a slight angle to the axis of the chisel. A flat elliptical face is best. A wide-faced chisel will cut into the sheet.

3. *After the head is knocked off the rivet, the shank may then be punched out with a punch* of smaller diameter than the hole.

205. Preparing the Damaged Parts for Repair.—All mutilated material should first be removed by the use of files, hacksaw, and chisels.

If a riveted joint is near the damage, it may be desirable to remove all material back to and including the joint.

Parts merely dented need not be cut out. The dents, however, should be straightened by bumping, using care not to leave hammer marks. See Job Unit No. 31 for method of patching dents.

Dents in thin sheets sometimes may be removed by the use of a large rubber suction cup similar to those used in clearing kitchensink drains.

All paint should be removed from the parts of the structure adjacent to the damaged portion, and the parts should be inspected carefully for cracks, or other indication of high stress. *Rivets may be sheared considerably without showing signs of failure.* It may be desirable to take out a rivet here and there around the damaged portion and examine it for signs of shear failure (Fig. 167) and for other signs of failure (Fig. 156).

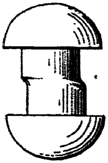

FIG. 167.—Rivet showing signs of shear failure.

206. Repair of Highly Stressed Members.—The repair must be applied so that all types of loading to which the member is subjected will be amply resisted. The types of loading are (see Chap. IX):

1. Tensile.
2. Compressive.
3. Shear.
4. Bending.

The loading which must be provided for may be determined in the following ways:

1. The design loads on the member may be obtained from the manufacturer's Approved Type Certificate *stress analysis* of the structure. The analysis will be on file at the factory.

2. The loading which a portion of the structure will carry before failure is called the *allowable load.* This load is always greater than (or equal to) the *design load.* The allowable load of a portion of the structure can be estimated from the original structure. As a simple example, to illustrate this point, suppose a strut is riveted at each end by two ⅛-in. aluminum-alloy rivets in single shear. We conclude at once that the allowable load

on the strut cannot be greater than the strength of two ⅛-in. rivets. Since we do not know the alloy of the rivet, we must assume the highest strength of ⅛-in. rivets (shear stress 35,000 lb. per square inch) as 430 lb. Thus the allowable load in the strut can be no greater than 430 × 2 = 860 lb. Thus a repair made to carry 860 lb. or more in the strut will be as strong or stronger than the original strut. See Par. 174 for detailed analyses.

3. A stress analysis made in the shop. *This is not to be recommended* even if the work is supervised by a competent engineer. In the first place, the work would be too expensive, and in the second place, it would not be reliable unless done in great detail, and checked by another competent engineer, as is done at the factory.

The second method is recommended as being the safest and simplest. There is very little opportunity for a mistake; and an engineering training is not necessary. A good mechanic who understands the airplane structure is competent to do the work.

JOB UNITS

Job Unit 26. Repair of Corrugated Stressed Sheets

Airplane Parts.—Flanges of box-wing beams (Figs. 137 and 138) and fuselage construction as in the Martin bomber.

Preparation for Repair.—Read Pars. 160, 161, 167, 206 and see Figs. 137 and 138.

Estimate of Strength Required.—The fact that the sheet is corrugated indicates that the parts are designed for compressive loads (see also Pars. 146 and 174).

The allowable load (see Par. 174) depends upon (1) the strength against buckling, (2) the strength against wrinkling, and (3) the rivet strength.

The repaired part should be as strong, at least, as the lowest of these three allowable loads.

In (1) we may assume a maximum of 40,000 lb. per square inch (see Par. 174).

In (2) the average experimental stresses given (Table XXI, see Ref. 1, page 212) will serve as a basis for a conservative estimate of the allowable stress.

In (3) the strength required of the repair is estimated on the basis of a riveted joint inward (toward the center of the airplane from the damaged portion). Count the number of rivets in a 10-in. width. Multiply the strength of one rivet (see Tables XVIII, XIX, and XX) by the number of rivets in the 10-in. width. Divide this total load by 10. The result is the allowable stress per inch width.

Example.[1]—In the repair of breaks in all corrugations, the corrugations are assumed to be subjected to a stress equal to the crippling stress (allowable stress). This is used to determine the size of reinforcing plate and the number of attaching rivets required.

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[1] As presented in "General Repair of Stressed Skin Structures," Engineering Report 432, The Glenn L. Martin Co.

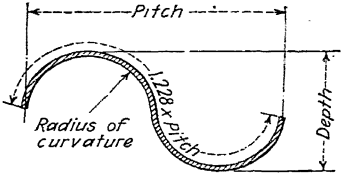

Fig. 168.—Dimensions of corrugations.

Table XXI.—Allowable Stresses in Standard Corrugations*

Pitch, in.	Depth, in.	Radius of curvature, in.	Thickness, in.	Allowable stress (axial), lb. per sq. in.
3.75	1.13	1.06	0.06	42,000
3.75	1.13	1.06	0.05	40,000
3.75	1.13	1.06	0.04	36,000
3.75	1.13	1.06	0.03	31,000
3.75	1.13	1.06	0.02	23,000
2.50	0.75	0.70	0.06	38,000
2.50	0.75	0.70	0.05	45,000
2.50	0.75	0.70	0.04	42,000
2.50	0.75	0.70	0.03	36,000
2.50	0.75	0.70	0.02	30,000

* These allowable stresses are the maximum allowed in design, increased by 20 per cent to insure ample strength in the repair.

A specific example is given to show the method:

1. Assume 0.051-in.-thickness corrugated skin.
2. Assume stress in corrugated sheet to be 40,000 lb. per square inch. (See estimate of strength required above.)
3. The reinforcement should be at least the gauge of the corrugation, or preferably one gauge heavier.
4. Assume the skin to be aluminum alloy 17ST, or equivalent in strength.
5. Assume rivets to be aluminum alloy 17ST, or equivalent in strength.
6. Refer to Fig. 169.
7. Area of cross section removed = 1.228 × 2.5 × 0.51 = 0.155 sq. in.
8. Load to be carried by patch = 0.155 × 40,000 lb. per square inch = 6200 lb.
9. Allowable bearing on ⅛-in. rivet (see Table XX) on 0.051-in. plate = 478 lb.
10. Allowable shear of ⅛-in. rivet = 368 lb. (see Table XX).

11. Number of rivets required = $\frac{6200}{368}$ = 17 rivets.

12. A minimum of 17 rivets should be used in front and behind the break to attach reinforcement to corrugation.

13. In width, the patch should be one complete corrugation wider than the break. In length the patch should extend 6 to 10 in. or more in front and behind the break, depending on the size of the break. The larger the break, the further the patch should extend.

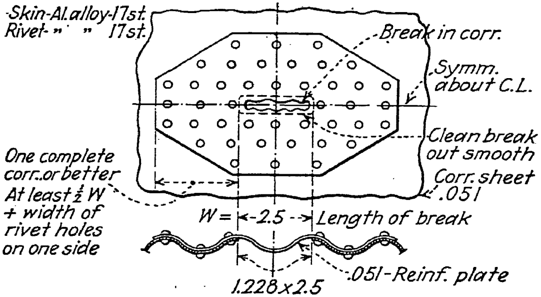

FIG. 169.—Patch on aluminum-alloy corrugation.

Job Unit 27. Repairs of Smooth Stressed Skin

Airplane Parts.—Stressed skin of wings using stringers; stressed skin in fuselage. (This does not, in general, apply to webs of beams.)

Estimate of Strength Required.—A smooth, flat sheet will carry only a small compressive load. Such a sheet, therefore, is not in general designed to carry compressive loads. Smooth skin is generally designed to carry tensile loads.

On account of the removal of material from the flat sheet for rivet holes, the allowable stress is not over 45,000 lb. per square inch for aluminum alloys. (Note that in the example, the Glenn L. Martin Co. uses 43,600 lb. per square inch).

Example.[1]—In smooth-skin structures, the maximum allowable tensile stress is reduced to 43,600 lb. per square inch to account for reduction in area due to rivet holes. All skin is assumed to be subjected to this stress. (This type of repair is only for smooth skin which carries stress. It does not apply to top skin on corrugation, cowlings, etc.)

In structures with thin skin, the reinforcement plate should always be at least one gauge heavier than the damaged skin. As the size of break increases, this difference in gauges should increase accordingly.

A specific example of smooth skin reinforcement is as follows:

1. Assume skin gauge = 0.028 in.
2. Assume skin stress = 43,600 lb. per square inch.
3. Assume material, aluminum alloy 17ST, or equivalent in strength. Refer to Fig. 170.

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[1] As presented in "General Repair of Stressed Skin Structures," Engineering Report 432, The Glenn L. Martin Co.

4. Area of cross-section of skin removed = 0.028 in. × 2.5 in. = 0.07 sq. in.

5. Load to be carried by patch = 0.07 sq. in. × 43,600 lb. = 3050 lb. (See Table XX.)

6. Allowable bearing of $\frac{1}{8}$-in. rivet on 0.025-in. sheet = 234 lb.

7. Allowable shear of $\frac{1}{8}$-in. rivet = 368 lb.

8. Number of rivets required = $^{3050}/_{234}$ = 13 rivets.

9. Thus, a minimum of 13 rivets should be used in front and behind break to attach the reinforcement of skin. See Fig. 170 for additional details.

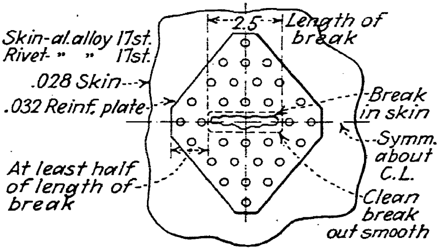


FIG. 170.—Patch on smooth stressed skin.

Job Unit 28. Repair of Strut

(Includes Vertical and Diagonal Web Members of a Wing Spar)

Airplane Parts.—Tubes in steel-tube fuselage, and vertical and diagonal web members of a wing beam. (Stringers have strut characteristics.)

Estimate of Strength Required (see Par. 174).—A strut may fail by (1) buckling, (2) wrinkling of the sheet metal locally, (3) by shear in rivets at the ends of the strut.

We may classify the damage as:

1. The strut is merely bent (buckled), and may be straightened.
2. A section of strut is so damaged (wrinkled) that it must be removed.
3. The entire strut is damaged beyond repair, and it must be replaced.

In (1), after the strut is straightened, it may be easily reinforced by clamping a reinforcing brace around the strut to prevent buckling. Figures 95 and 171 show the arrangements of this type of reinforcement. The reinforcement should be amply long; for example, half the length of the strut. The thickness of the sheet should be as great as, or greater than, the thickness of the strut walls. A minimum amount of riveting through the strut is best, as it is only necessary to hold the reinforcement snugly in place. Rivets $\frac{1}{8}$ in. in diameter spaced at a pitch of about 1 in. will be ample for most repairs. In riveting the reinforcement without piercing the strut, the mechanic need feel no restraint.

The condition in (2), in general, could hardly occur without damage to other parts of the structure, especially to other parts of the same truss. Other parts should therefore be inspected carefully for breaks, wrinkles, and especially for sheared rivets. (Read Par. 205, in regard to inspection of sheared rivets.)

The method of repair shown in Fig. 171 is also the method used in this case. The riveting of the reinforcement, however, is the major problem. The rivets must carry the entire load of the strut in shear. It is desirable to use rivets in double shear whenever possible, as only half the number of rivets required in single shear will be necessary.

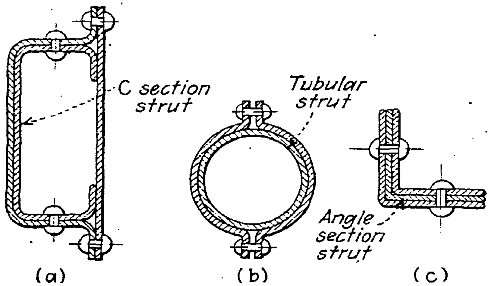


FIG. 171.—Reinforcing a bent strut.

Example.—To illustrate the principle involved, consider Fig. 172:

1. Assume aluminum alloy, 17ST.

2. Assume a stress in the original strut of 40,000 lb. per square inch (s Par. 174). The area of cross-section cut out is a fraction less than 2 × = 0.25 sq. in.

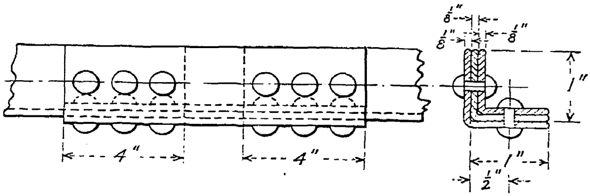


FIG. 172.—Splicing an angle-iron strut.

3. Load to be carried by patch = 0.25 sq. in. × 40,000 lb. per square inch = 10,000 lb.

4. Using $^{3}\!/_{16}$-in. rivets, because larger rivets are hard to drive, the joint is weakest in rivet shear.

5. The load allowed on each rivet (double shear) is 828 × 2 (see Table XVIII) or 1656 lb.

6. Number of rivets on each side of cutout = $^{10000}\!/_{1656}$ = 6 rivets.

7. A rivet spacing of pitch about 1 in. is reasonable. The splice should overlap about 4 in. or more, depending on the space. (An overlap of 2 in., however, will develop the full strength of this strut.)

8. Riveting should be along the middle of the flanges of the original strut angle bar. The purpose of this is to prevent eccentric loading which tends to bend the strut.

Other Strut Cross Sections.—The same procedure as given in the example may be followed in all strut repairs of this nature. Two rules, however, should be emphasized:

1. The reinforcement should be built up entirely around the cross section of the strut, the original strut section being balanced in the surrounding reinforcement.
2. The rivets should be located so that the loading is transmitted through the reinforcements without causing bending; that is, the rivets should be balanced around the original cross section.

Job Unit 29. Replacement of an Aluminum-alloy Strut

Study Repair of a Strut, Job Unit 28, and How to Remove Rivets, Par. 204. Also study the forming of aluminum alloys, Chap. X. The strut must, of course, be a duplicate of the original in every respect.

Job Unit 30. Repair of a Stringer

Airplane Parts.—Compression members in the fuselage (see Par. 153) and in wings (see Par. 167); also compression members in some engine nacelles, in control surfaces, and in some fins and stabilizers.

Estimate of Strength Required.—Stringers may, for the purpose of this analysis, be considered as struts supported by the skin of the fuselage, wing, etc. We can assume, therefore, that for aluminum-alloy materials, the upper limit of the allowable stress is 40,000 lb. per square inch, and that repairs made on this basis will be of the required strength. See, therefore, Job Unit 28, Repair of a Strut. The damage may be classified as outlined for the strut. For the purpose of the application of instructions in this job unit, however, a part of the skin must be considered with the stringer. To be on the safe side the skin on each side of the stringer halfway to the next stringer may be considered as a part of the strut.

Figure 173 shows the proper way of removing rivets from stringers. As noted, the chisel should cut parallel to the stringer, and a bucking bar should be held against the opposite end of the rivet.

Examples.—Figure 174 shows a repair of a minor injury to a stringer as recommended by Dornier (Germany). Figure 174*a* shows the dent in the stringer. The stringer is of the closed type (hat section, see Fig. 125), so holes are cut in the skin for access in smoothing out the dent, for removing rivets, and for driving rivets. After the stringer has been bumped back in place, it is reinforced by a channel *B*, using the rivet holes already in the stringer. The holes cut in the skin for access are then covered by a cover plate of material a gauge thicker than the skin. No additional holes are drilled for this plate as will be noted.

The objectional feature of this repair is that the outside surface of the skin must be marred. As an alternative method, the following may be considered:

1. Cut holes in the side of the stringer, instead of in the skin, to get inside the stringer to bump it back in place, to remove rivets, and to drive rivets.
2. Remove all rivets for about 3 in. on each side of the repair.

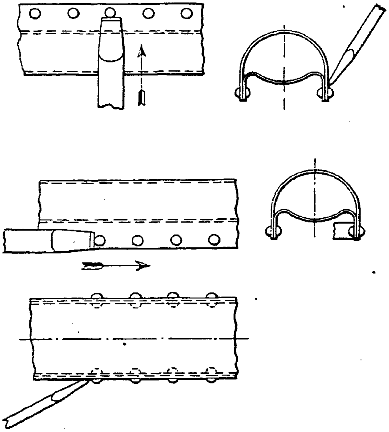
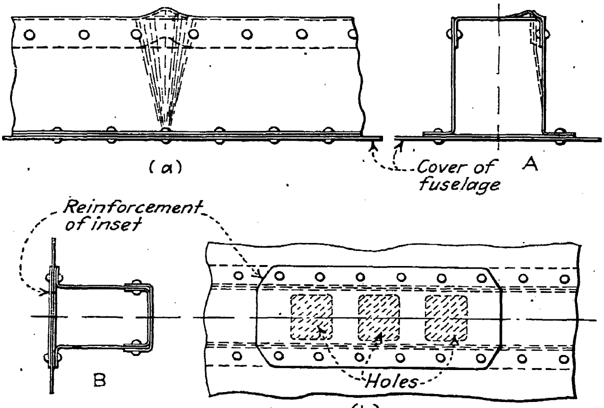


FIG. 173.—Removing rivets from stringer. Upper, wrong way; lower, right way.



(a)

(b)

FIG. 174.—Dornier method of repair of stringer.

3. Form a hat section of the same thickness of materials as the cover plate, about 6 in. long, to fit over the stringer. Cut holes in the side of the hat section to correspond to the holes cut in the stringer (see Fig. 175).

4. Fit the reinforcing hat section over stringer, and rivet in place as in Fig. 175.

NOTE: The additional area of cross section provided by this reinforcement is sufficient to amply regain the strength lost by cutting the holes in the sides of the stringer. The holes should be as far from the ends of the patch as is convenient for working.

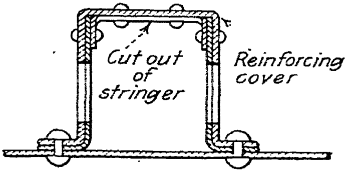


FIG. 175.—Repair of stringer beam flange.

Job Unit 31. Repair of a Semistressed Fuselage

Airplane Parts.—This includes the repair of the skin and formers of the skin. The Boeing 247 fuselage is taken as an example. This fuselage (Fig. 176) has four longerons which constitutes the major frame of the fuselage. The skin provides the resistance to torsion. It is reinforced by small hat sections called formers. These are called formers because they form the skin to the shape of the fuselage. They are also stiffeners, since they stiffen the skin against wrinkling.

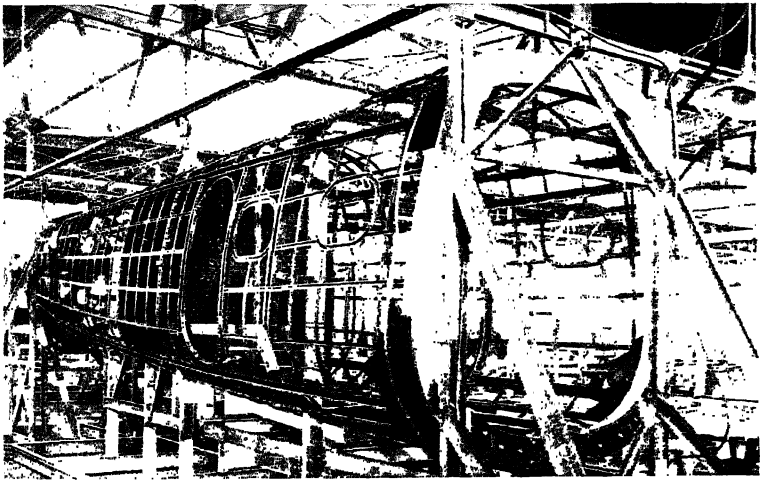
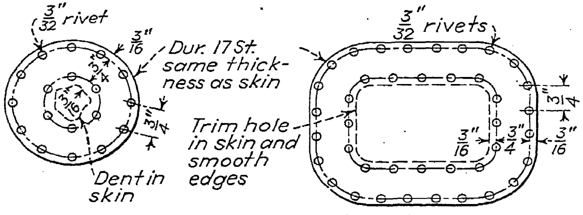


FIG. 176.—Semi-monocoque fuselage frame. Boeing 247. *(Courtesy of Boeing Airplane Co.)*

Estimate of Strength Required.—The members in this class are subjected to stresses, but in general the stresses are fairly low since the buckling of the skin and formers, and not the strength in tension, is the criterion of strength.

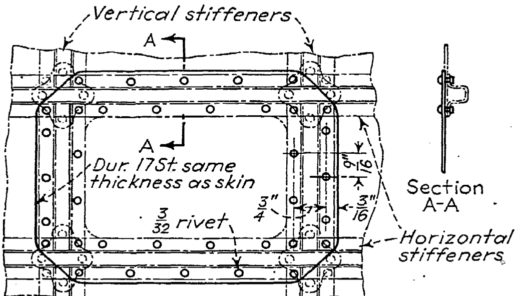
The calculation for the allowable stress is not simple. It is best, therefore, in this case, to adopt standard forms of repairs which will be strong enough to provide for the strength in all cases. The following examples may be assumed to be standard for this general type of construction.

Examples.[1]—Figure 177 shows the repair of a dent in the skin. It is the general practice to smooth out the dent, and cover as shown in Fig. 177*a*.

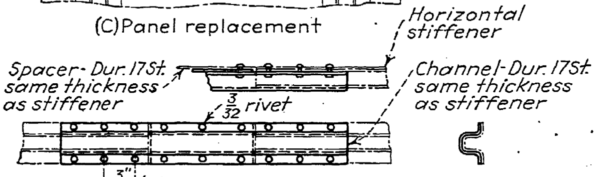


(a) dent repair (b) cut repair

FIG. 177.—Repair of dent and cut in fuselage semistressed skin.



(C)Panel replacement


Horizontal stiffener
Spacer-Dur. 17St. same thickness as stiffener
3/32 rivet
Channel-Dur. 17St. same thickness as stiffener
3/4"

(D) Stiffener splice

All rivet spacing is approx. Rivets and plates to be set in wet red primer

FIG. 178.—Repair of semistressed-skin fuselage.

Figure 177*b* shows the repair of a cut.

Figure 178 shows instructions for replacing a panel and for splicing a stiffener. Instructions are given in detail in the figures.

It is noted in the Manual that "in case of major repair or rebuild of fuselage, it is suggested that complete new sections of skin and formers be installed. Each main repair base should have on hand prints of Drawings 15-2485, 15-2486 and 15-2487, for this purpose."

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[1] As given in "Maintenance Manual of Boeing 247."

AUTHORS' NOTE: This, in general, should be the procedure for major repair or rebuild of any airplane structure.

Job Unit 32. Standard Repair of Small Holes (¼ In. to 1 In. in Diameter) in Thin Sheets

Airplane Part.—The thin skin cover of a wing, fuselage, fin, stabilizer, or control surface. (Not, in general, suitable for webs of wing spars.)

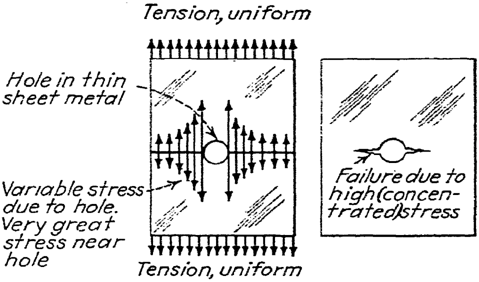
Tension, uniform
Hole in thin sheet metal
Variable stress due to hole. Very great stress near hole
Tension, uniform
Failure due to high (concentrated) stress

FIG. 179.—Failure in skin due to small holes.

Estimate of Strength Required.—Figure 179 shows the effect of a small hole in a thin stressed skin. Note that on each side of the hole the stress, due to the elasticity of the material, is increased very greatly. The loss in area due to a ¼-in. to 1-in. diameter hole will not, in general, be large enough to reduce the strength of the entire panel below its design value. The purpose of the patch then is to prevent the hole from spreading in the manner indicated in Fig. 179.

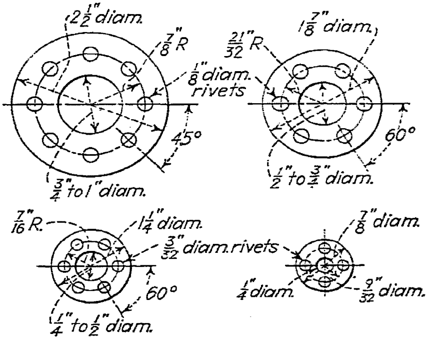

FIG. 180.—Standard reinforcement of small holes in thin sheets.

Examples.[1]—Figure 180 shows the standard reinforcement for holes up to 1 in. in diameter. Whether the reinforcement washers are single or double will depend on the nature of the stress, vibration, etc. In any case the thickness of each washer shall be at least equal to the thickness of the sheet.

Job Unit 33. Repair of Crack in Engine Cowl, Fillet, Wing Tip, and Other Nonstressed Sheets

Airplane Parts.—Besides those parts mentioned in the title this includes also the fuselage nose of a bimotored airplane, and other fairing surfaces.

Estimates of Strength Required.—These parts are supposed to be nonstressed. They are, however, subjected to vibrations and to the buffeting of the air stream. These stresses may become quite large, as a crack certainly indicates. However, since the safety of the airplane is not involved in the strength of these parts, the standard practice in repair is to stop the crack by drilling a small hole, ⅛ to ¼ in. in diameter, at each end of the crack and to cover the damaged portion with a patch bumped to fit the surface.

Excessive cracking in an engine cowl indicates that undue stress is being transmitted to it. The cowl is a collar around the engine mount. The engine mount is supposed to twist in this collar as the engine vibrates torsionally. (In general engine mounts are set in rubber so that this oscillation is possible. It relieves the load in the structure and prevents the vibration from being transmitted to other parts of the airplane.) It is therefore apparent that the cowling should be attached to the structure with allowance being made for the movement of the mount. If this allowance is not made, the cowl is subjected to a very heavy oscillating load which soon cracks the material.

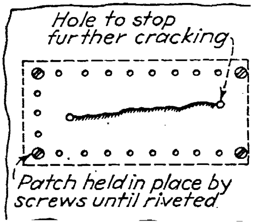
Hole to stop further cracking
Patch held in place by screws until riveted

FIG. 181.—Repairing crack in cover, such as engine cowl.

Example.—Figure 181 shows a repair of a vibration crack. The procedure is as follows:

1. Drill a ⅛- to ¼-in. hole at the end of the crack. This distributes the stress over a broader area, thus preventing a continuation of the crack.
2. Cut a reinforcing plate of the same type and thickness as the cowl material and large enough to extend well beyond the crack on all sides.
3. Bump the plate to the proper shape and drill the corner holes.
4. With the plate held in place, drill through the corner holes into the cowl.
5. Hold the plate in place by screws (that fit) placed in the corner holes. (It may be desirable, in order to retard corrosion, to paint the under side of the plate with a good grade of bitumastic paint before putting the plate in place.

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[1] As presented in "General Repair of Stressed Skin Structures," Engineering Report 432, The Glenn L. Martin Co.

6. Lay out and drill the remainder of the holes. Holes should be for 3/32- to 1/8-in. rivets.
7. Insert flat-headed rivets, heads out, and head on the inside.
8. Remove screws in the corner holes and rivet.

Job Unit 34. Repair of a Break in a Stressed Fuselage

Estimate of Strength Required.—This is the same as for a flat stressed skin (see Job Unit 27).

Example.[1]—(See Fig. 182.) The repair of the side skins of the fuselage, if only a crack develops is a little different from the repair of a hole. In this case, it is not necessary to clean a smooth hole the full length of the crack. However, it is important that a small round hole be drilled at each end of the crack. These holes will tend to prevent the crack from spreading and thus insure a better repair job. The method of finding the number of rivets required and size of patch plate is the same as used in smooth stressed-skin repairs. See Job Unit 27.

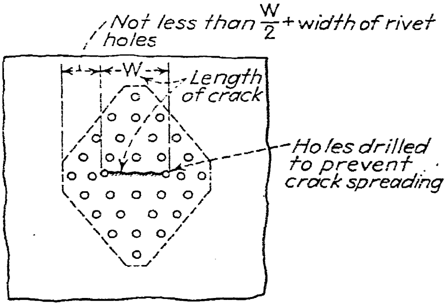
Not less than $\frac{W}{2}$ + width of rivet holes
1
W
Length of crack
Holes drilled to prevent crack spreading

FIG. 182.—Repair of break in stressed-skin fuselage.

Job Unit 35. Repair of the Fuselage Bottom Skin

Airplane Parts.—A belly landing, that is, with wheels retracted, as is sometimes desirable or necessary in a forced landing in a restricted space, quite generally rips up the bottom of the fuselage. This is especially true for a center-wing airplane.

Estimate of Strength Required.—Entire sections are replaced in this case; and they are replaced according to the design drawings and parts obtained from the manufacturer. The repair is a major one.

Example.[1]—With reference to Fig. 183:

1. Remove rivets attaching lower corrugations to longerons and remove entire corrugations in damaged area. The extent of the corrugations

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[1] As presented in "General Repair of Stressed Skin Structures," Engineering Report 432, The Glenn L. Martin Co.

removed in the fore and aft direction is to be governed by the transverse splices.

2. Remove all lower rings, that are damaged, up to splice. In case it is not necessary to remove the entire lower ring, the ring should be cut well above the damaged portion and a new ring spliced on. This splice should be made the same as the splice connecting upper and lower sections of original ring.

3. Rivet side skin to new lower-ring sections.

4. Rivet new section of bottom corrugated skin to rings. This skin should be ordered from the Martin Co. as it is difficult to flatten the corrugations at the center line of fuselage and at the longerons. If flattening is tried it should be done on heat-treated corrugated sheet as the corrugated sheet buckles badly during heat treatment.

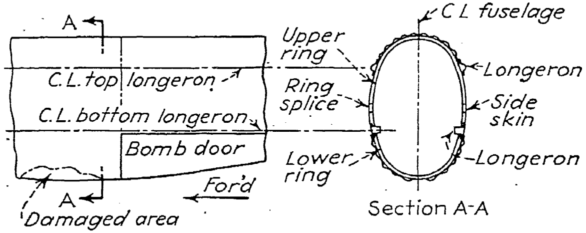


FIG. 183.—Repair of fuselage after belly landing.

5. All splices necessary in smooth or corrugated skin must be made with the same lap and the same rivet spacing as used in adjacent splices.

AUTHORS' NOTE: The general procedure outlined in this specific example is an excellent guide for major repairs of this nature. It would not be desirable or possible to give specific examples for all airplanes.

Job Unit 36. Repair of Metal Trailing Edge of Fabric-covered Surfaces

Airplane Part.—The trailing edge, from the rear spar back, of some airplanes is covered with fabric. The purpose is to make the wing lighter, and to retard wing fluttering. The frame of this portion, including the railing edge, is made of metal.

Estimate of Strength Required.—The stress in the member is bending due to the pull of the fabric and to the air load. A reinforcing plate of material of gauge thickness a little greater than that of the original member, and riveted by a few 3/32-in. to 1/8-in. rivets will make the member overstrength.

Example.[1]—With reference to Fig. 184:

1. In the case of a damaged trailing-edge strip, the method of repair is comparatively simple. The damaged portion is cut away. It is usually most convenient to locate the extremities of the cut centrally between trailing-edge ribs. This permits the splice clips, for attaching the new section, to be installed easily.

[1] Recommended by Glenn L. Martin Co.

2. Figure 184 shows a typical method of splicing ends of trailing-edge strips.

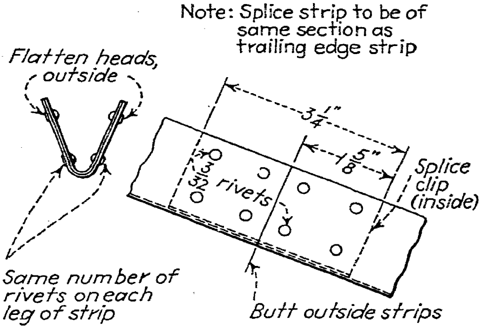
Job Unit 37. Repair of a Spar Web

Airplane Part.—Read Pars. 159 to 167.

Estimate of Strength Required.—There are two classes of webs.

1. Thin webs which are supposed to wrinkle under load.
2. Webs which are designed on the basis of nonwrinkling.

The repair of the wrinkling-type web is very difficult. It would be desirable to replace the entire web if practical. It is not desirable to put a patch on the web, because of the wrinkling of the web and because of the bad effect of the rivet holes. A repair requiring no additional rivet holes is best.



Note: Splice strip to be of same section as trailing edge strip

Note: Fabric to be repaired according to standard methods

Fig. 184.—Repair of trailing edge.

If there is room to double the web in thickness, a satisfactory repair can be made as follows:

1. Consider four adjacent vertical web members which we may designate as 1, 2, 3, and 4. Call the bays between these web members *A*, *B*, and *C*. Assume the damage to the web is in bay *B*, which will be between vertical web members 2 and 3.
2. Cut out the damaged web to within about 1 in. of verticals 2 and 3.
3. Cut a new web, duplicating the old web, to extend on one side 1 in. past vertical 1 and on the other side, 1 in. past vertical 4. This makes the new web cover bays *A*, *B*, and *C*. Rivet the web in place, using the original holes.
4. In this repair, the web in bays *A* and *C* is doubled. This is necessary to transfer the load from the old web to the new web, and then from the new web to the old web again. This transfer, in general, cannot be successfully made by a vertical splice in the web, whether the splice be a lap joint or a butt joint.

The repair of a nonwrinkling web is a fairly simple job. The repair must be designed to resist shear.

The design shear value for aluminum alloy is not over 35,000 lb. per square inch; hence if this figure is used, the repair job should be of the required strength. Study Pars. 164 to 167 and the related figures. The shear acts vertically and horizontally with the same value.

Example.—The following example is for the web assumed not to buckle.

NOTE: A simple, and at the same time exact, rule cannot be given for determining whether a web is of the nonbuckling type or not. The manufacturer can readily obtain this information from the stress analysis of the job. If the thickness of the web is greater than a hundredth of the distance between two vertical supports of the web, it is a nonwrinkling web. For example, if this distance is 5 in. and the thickness of the web is 0.051 in., the web is a nonwrinkling web. This is a very conservative test; and the web may be nonwrinkling with a skin of less thickness or with a spacing of verticals greater than 5 in. See Fig. 185:

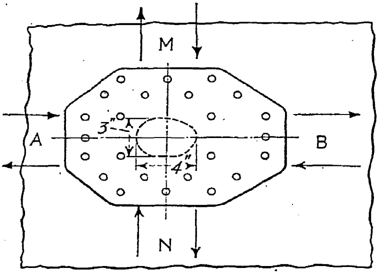


FIG. 185.—Repair of thin sheet metal in shear (web of beam).

1. Assume web thickness of 0.064 in. Assume material to be aluminum alloy 17ST or equivalent.
2. Longitudinal shear to be resisted by the repair = 35,000 lb. × 0.064 in. × 4 in. = 8,960 lb. Call it 9,000 lb.
3. Vertical shear to be resisted by the repair = 35,000 lb. × 0.064 in. × 3 in. = 6720 lb.
4. Number of $^{3}/_{16}$-in. rivets on each of upper and lower side of line *AB* (see Table XVIII). = $^{9000}/_{828}$ = 11 rivets.
5. Number of rivets on each side of vertical line *MN* = $^{6720}/_{828}$ = 9 rivets.
6. See Fig. 185 for approximate distribution of rivets.
7. The size of the patch will depend upon the space available. The rule to follow is to make it about three times the dimension of the hole in each direction, if posible, but in any case large enough to satisfy the standard rules of riveting. (See Par. 195.)

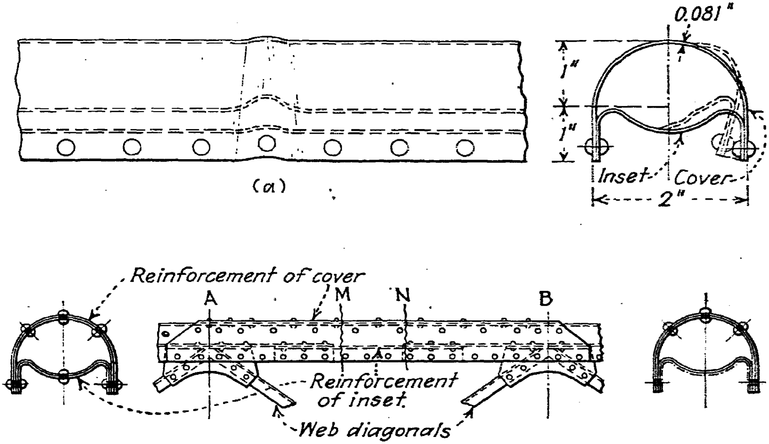
Job Unit 38. Repair of the Flange of a Beam

Airplane Part.—Flanges of wing spars, and vertical fin and horizontal stabilizer spars.

Estimate of Strength Required.—The flange of an aluminum-alloy spar, in general, is designed for a compressive load. It falls therefore under the classification of struts. In this case, the design allowable stress is 40,000 lb. per square inch. The design stress in tension, allowing for rivet holes will not be over 45,000 lb. per square inch, hence if the higher value were used, all eventualities would be met.

The total load to be carried by a repair is therefore 45,000 times the area of the cross section of the flange.

In general, it would not be difficult to make the flange repair stronger than the original flange.



(a)

(b)

Fig. 186.—Repair of dent in flange of spar.

Example.—Figure 186 shows a neat repair of a flange, recommended by Dornier (Germany), which exhibits all the fundamentals of compression-member reinforcements.

Figure 186*a* shows the damaged flange. Figure 186*b* shows the reinforcements in place. It will be noted that the rivets have been removed and that reinforcing plates entirely encircle the original flange. The reinforcement is long enough to extend well over two adjacent flange supports *A* and *B*, and ties in the diagonals of the web members. Three methods may be used in riveting through the walls of the closed tube:

1. Tubular rivets could be used.
2. A device similar to that of Fig. 157 could be used.
3. Holes could be cut in the insert (lower part of flange) for inserting and bucking rivets.

If it were necessary to remove a portion of the flange, for example, the portion between *M* and *N* in the figure, the form of the repair would be the same. The thickness of the material would be the same or one gauge thicker than the original flange thickness. The rivets necessary on each side of the cut-out section would be calculated as follows:

1. Area of cross section removed is a little less than $(4 \times 1 \text{ in.} + 2\pi \times 1 \text{ in.}) \times 0.081 \text{ in.} = 10.28 \text{ in.} \times 0.081 \text{ in.} = 0.835$ sq. in.
2. The load to be carried by the rivets is $0.835 \times 45{,}000$ lb. per square inch $= 37{,}600$ lb.
3. For this thickness of material, $\frac{1}{4}$-in. rivets would be used, or else the size already in the flange.
4. Strength of $\frac{1}{4}$-in. rivets in shear $= 1472$ lb. (See Table XX.)
5. Number of rivets required $= {}^{37600}\!/_{1472} = 26$ rivets.
6. If $\frac{3}{16}$-in. rivets were used, the number required would be

$$^{37600}\!/_{828} = 46 \text{ rivets.}$$

7. The figure shows the arrangement for about 50 rivets.

Job Unit 39. Repair of the Leading Edge of a Wing

Estimate of Strength Required.—The leading edge of a wing may or may not be a stressed member of the wing structure.

1. If the leading edge is attached to the wing so that it may be readily removed for inspection, etc., by the removal of a few screws or bolts, it is not a supporting member of the wing. The leading edge in this case is required to carry only the air load distributed over its surface. These air forces are, however, quite large, and the buffeting on weak or loose sections is quite violent. No special calculation is necessary in determining the strength required; but care should be used that the original strength, and especially the original rigidity, are maintained. As to the size of rivets, thickness of sheet, etc., follow the practice indicated in the original structure. Small holes may be repaired according to Job Units Nos. 31 and 32. If the damage is more extensive, such as may be inflicted by fence posts, etc., in a forced landing, then a new section should be built in with the same characteristics as the original section. If a new section is inserted, it should terminate at each end by lapping over nose ribs far enough to permit satisfactory riveting to these ribs.

2. If the leading edge is an integral part of the wing, such as in the case of a single-spar wing (see Par. 170), then the leading edge is a major stress member of the wing and as such must be repaired by a stress-carrying patch.

The principal stress to provide for is shear, since the leading edge of a single-spar wing together with the spar form a tube which resists twisting loads on the wing. An allowable skin stress of 35,000 lb. per square inch may be assumed. A repair designed on this basis will be satisfactorily overstrength.

Example.—The calculation will be the same as in Job Unit 37.

If the repair is extensive, a section of the leading edge may be removed and a new one installed, using the removed section, or an adjacent section nearest the root of the wing, as a pattern.

Job Unit 40. Repair of Metal Nose Covers on Fabric-covered Wing Flaps

LEADING EDGES OF CONTROL SURFACES

Example.[1]—See Fig. 187. The repair of this nose cover requires the removal of all fabric adjacent to the damaged portion. The size of this cover plate prohibits the use of handholes as an aid in attaching the repair sheet. The simplest method is to remove a complete section of the nose cover and install a new one. Lap splices should be made at a nose rib as this insures a rigid joint. Tools for bucking the attaching rivets may be inserted between the torque tube and the short side of the nose cover. The gauge of the repair sheet should be the same as the original nose cover.

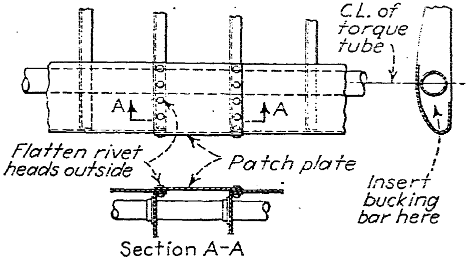


FIG. 187.—Repair of metal nose covers on fabric-covered wing flaps.

Repair fabric according to standard methods. (See Chap. XIII.)

AUTHORS' NOTE: This type of repair is also satisfactory for the leading edges of control surfaces.

Job Unit 41. Repair of Metal-covered Stabilizer

(Applies to Vertical Fin also)

Example.[1] See Fig. 188. In this type of structure all sections are completely closed, making any repair to the skin rather difficult. Breaks in the skin that can be cleaned out to a hole of size not over 5 in. in diameter can be repaired by installing a standard handhole. The hole should be reinforced by attaching a heavy ring on the inside of the skin. This ring should be about two gauges heavier than the skin. The cover plate should be at least the gauge of the skin. A gauge heavier is preferable. The cover plate must be screwed on, requiring the installation of elastic stop nuts, or a provision for tapped holes in the reinforcing ring. The use of Elastic Stop Nuts is usually most convenient.

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[1] As recommended in "General Repair of Stressed Skin Structures," The Glenn L. Martin Co.

In case the damage is too large to repair by means of a handhole, the entire panel may have to be removed; or at least a large portion of it. If the entire panel is replaced, the new panel should be riveted to the front spar first. This permits the rear end to be raised, and the introduction of bucking tools through the opening. To aid in riveting, a handhole may be assembled on the repair plate before the plate is attached to the stabilizer.

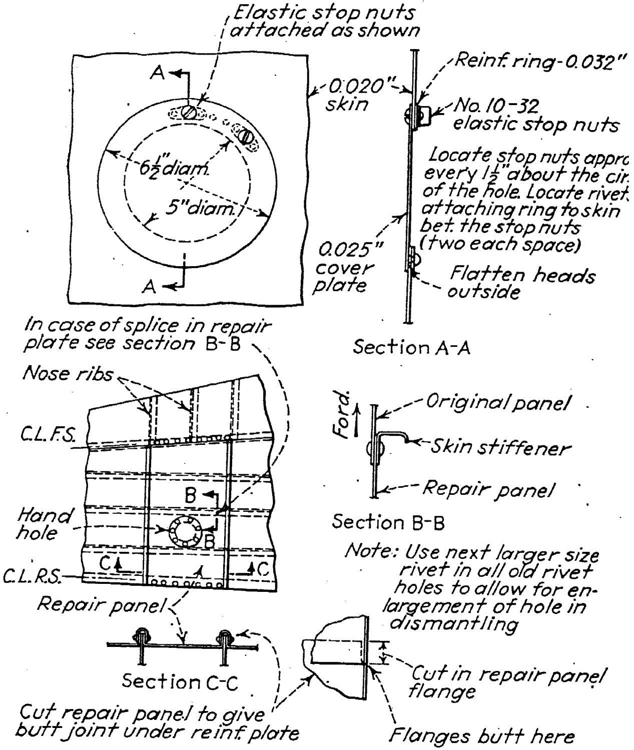
Elastic stop nuts attached as shown
A
A
6½" diam.
5" diam.
0.020" skin
Reinf. ring-0.032"
No. 10-32 elastic stop nuts
Locate stop nuts appro every 1½" about the cir. of the hole. Locate rivet attaching ring to skin bet. the stop nuts (two each space)
0.025" cover plate
Flatten heads outside
Section A-A
In case of splice in repair plate see section B-B
Nose ribs
C.L.F.S.
B
B
Hand hole
C
C
C.L.R.S.
Repair panel
Ford.
Original panel
Skin stiffener
Repair panel
Section B-B
Note: Use next larger size rivet in all old rivet holes to allow for enlargement of hole in dismantling
Section C-C
Cut repair panel to give butt joint under reinf. plate
Cut in repair panel flange
Flanges butt here

FIG. 188.—Repair of metal-covered stabilizer.

If only a portion of the panel is removed, the transverse splice should come at a skin stiffener. A handhole may also be incorporated in this repair plate if desired. The method of attachment should be the same as that for the entire panel repair.

In case any of the above repairs are necessary in the flotation compartment, the watertight riveting and sealing conditions must be met.

The above instructions are applicable to repairs to the nose cover of the stabilizer.

Job Unit 42. Repairing Seaplane Floats

Example.[1]—(See also Removal of Rivets, Par. 204, and heading Rivets in Repair Work, Par. 196.)

Straightening Dents.—If a float has been slightly dented, it can be hammered back into shape by placing a flat piece of wood against the deformed part and hammering on the projecting material with a wooden mallet. A stick of wood pounded with a hammer will often reach spots where a mallet cannot be used. Where dents have produced very sharp bends in the metal, they can still be hammered out, but in this case it is advisable to reenforce them by putting on a patch (as described in the paragraph on Patching), even though the flattening out of the metal has not caused any apparent cracks.

As previously noted, the portion of the bottom just forward of the step plays a most important part in the take-off characteristics of the floats, and if it is even slightly dented or deformed, it may make itself felt by a tendency to porpoise or nose over in high-speed conditions on the water. For this reason, even small dents must be corrected in this area, but with this exception they had probably best be left alone, since hammering changes the molecular structure of the metal, weakening it and making it more subject to corrosion, and in the absence of heat-treating facilities as little should be done as possible.

Patching.—Welding any part of the floats must be absolutely prohibited since it is extremely difficult to accomplish and at the same time would destroy the strength of the heat-treated metal as well as the Alclad protective film. For this reason where the metal has been cracked, punctured, or requires reinforcing, a patch is always applied, and the operation should be performed with care.

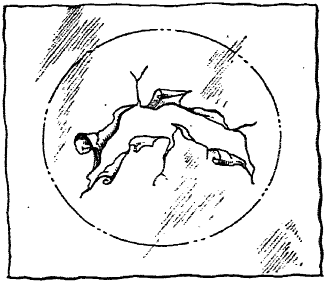

FIG. 189.—Cut away damaged section along dotted line.

Never try to patch over a dented or torn piece of metal until it has been hammered back into shape as described above. Before making a patch, the paint should be removed and the region of the damage carefully examined for cracks or tears radiating from the edges; and these should all be cut away. Having determined the extent of the damage, the edges should be trimmed out with shears or a hacksaw, so as to form a symmetrically shaped hole with sound metal all the way round, and carefully smoothed down with a file. (See Fig. 189.)

The next step is to cut out a patch large enough to overlap the edges of the hole by approximately ⅝ in. all the way round, using Alclad sheet, one or two gauges heavier than the damaged material. A row of rivet holes should then be laid out and center-punched on the patch, ¼ in. in from the edges of the patch with a spacing of ⅜ in. on centers. Unless the material is over

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[1] As recommended in "Service Manual," Edo Aircraft Corporation.

0.040 in. thick, rivets of $\frac{1}{8}$-in. diameter should be used; for heavier gauges, $\frac{5}{32}$-in. rivets should be used.

To apply the patch (see Fig. 190) three or more holes should first be drilled through both the patch and the piece under repair, and machine screws should be put in so as to hold the patch in place until the balance of the drilling and riveting is completed. Be sure to have the patch set firmly against the float before drilling or the holes are likely to be found out of alignment when riveting is started. *The patch should always be applied from the outside,* and drilling will be greatly facilitated if a block of wood is held against the metal from the inside. To insure watertightness and to prevent corrosion, cotton cloth or seam tape, thoroughly soaked in Bakelite seam compound should be placed between the patch and the metal under repair. This same procedure should be followed in making up any other watertight joints or seams in the repair of the floats, and although the cotton is omitted in non-watertight joints, such as auxiliary framing between bulkheads, the surfaces should none the less be painted with seam compound before riveting in place.

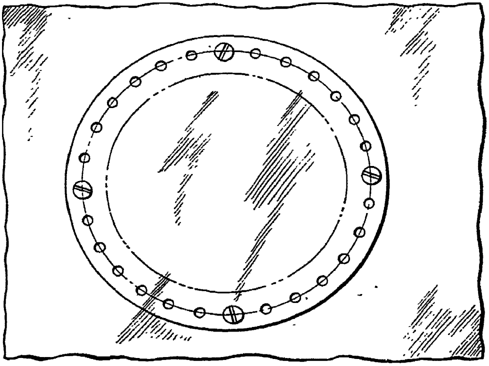

FIG. 190.—For drilling and assembly, hold patch on with machine screws.

Patching with Screws.—Where rivets are not available or where, because of lack of time or facilities, it is impractical to use the rivets, Parker-Kalon thread-cutting metal screws or steel machine screws may be used for temporary repairs. Both are put in with heads on the outside and can generally be purchased from any hardware jobber. Since *Parker-Kalon screws* are set with a screw driver, they have the advantage of not requiring any attention from the inside of the float, which is of great value in emergency use and where difficult spots must be reached. *It is very important, however, to use exactly the right size of drill* before setting them in place, since otherwise their effectiveness will be much impaired, and for this reason a special drill of the correct size is included in the standard Edo repair kit. The correct size will also generally be found marked on the box of screws. The screws should be long enough to protrude through the sheets with one thread showing. Both machine and Parker-Kalon screws are, of course, only temporary and should be replaced with rivets at the first opportunity.

Removing Decks (See Fig. 191).—Removing the decks gives good space to work in and often means quicker and better results in case of a general overhaul or major repairs. It is accomplished by knocking out the rivets, and where the damaged area is localized, it may save time to remove only the section of deck between two bulkheads. This is done by cutting the deck sheet with a drill and hacksaw. To make the cut strong and watertight when replacing it, an extra strip about 1½ in. wide is lapped over the joint. In the shop two men can generally remove the decks of an average size pair of floats in a morning and put them back in a day.

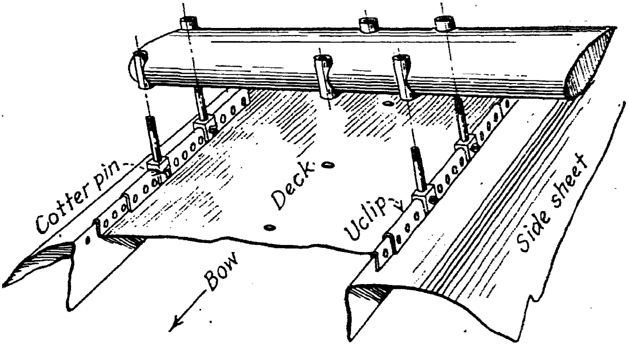

FIG. 191.—Removing decks.

The same holes are used in putting decks back. The rivets fastening the deck to the stringers and bulkheads are put in and bucked from the inside by reaching through the handhole covers, and riveted in the usual manner. In case of floats having an outside seam, however, the rivets can be squeezed with a considerable saving in time. A large wire cutter about 3 ft. long with specially cupped jaws can be used for the purpose. Such a tool can be supplied by Edo or made up at any machine shop.

Special Precautions must be taken in removing and replacing decks on those float models in which the spreader tubes are attached to the upstanding seams (see illustration) in order to be sure that the strength of the fitting is not impaired. The danger lies in improperly replacing the steel U-clip, and every effort should be made to use the original holes for the rivets, since drilling new holes would seriously weaken the vertical stiffener. If new deck and slide sheets and vertical stiffeners are used, it is extremely important to see that the U-clip is driven firmly home before drilling since otherwise the holes might only pierce the edge of the metal, resulting in a complete loss of strength in tension.

Replacing Sheets.—Where a large area is damaged it makes a better job to remove a section of the sheets instead of trying to put in a very large patch. Such a replacement should extend at least the length between two bulkheads, and the joints should be made at the bulkheads, rather than between them. In splicing on a new sheet a double row of rivets should be used on the bottom, although a single row will suffice on the side. In most cases it is easier to put both rows on the flanged side of the bulkhead. Although it takes more time, it makes a better job if a reinforcing strip is put on the inside of the bulkhead flange. *It is very important that the old holes in the original metal match exactly with the holes drilled in the replacement sheet or patch.* Otherwise, if new holes are drilled between the old holes, this procedure will so weaken the sheet as to affect its strength seriously.

To insure matching of the holes either drill the patch from the inside using the old holes as a guide, or else mark the patch very carefully with a pencil so that the center of the mark is exactly over the center of the hole. In thin sheets, in cases where a drill will not reach a hole from the inside, it is possible to push a sharp instrument, such as an ice pick or center punch, hard up against the inside of the sheet. By hammering lightly on the outside of the sheet with a mallet a slight projection results which can serve to locate the hole.

Repairs of Buckling Internal Failures.—If the side sheets have been slightly wrinkled by very hard landings, they can be bumped out by bracing the outside of the float at the bulkheads and hammering from the inside with a board hit by a wooden mallet. *The stringers can generally be straightened* in the same manner, and it is then advisable to rivet some extra ones on the inside to keep the damage from spreading. If the float is buckled to a point where there is a sag of more than ¼ in. in the deck line or the bottom stringers in the flat portion forward of the step, or if the side-sheet wrinkles are very sharp, it will probably be necessary to remove the deck to make a thorough inspection, and replace those stringers which are bent.

There is also a possibility that the sheets will have been strained so that they may crack when straightened. If this is the case, it is generally advisable to remove the damaged ones and splice on a new section.

In the case of a float which has been seriously buckled the bulkheads should also be carefully examined for buckling or cracks, particularly at the bottom near the flange. If the buckle is not bad, it can be hammered out and a reinforcing plate fastened on. This should usually be flanged over and fastened on the opposite side from the existing flange. If the buckling is so bad that the bulkhead has cracked, it is advisable to saw out the bottom half and rivet on a new portion. Bulkheads of production floats are generally stamped at the factory to standard sizes, and it is usually easier and cheaper to obtain a new one than to try and form one. Except in cases of minor buckling, it will generally be necessary to remove the bottom as well as the deck in order properly to replace a section of bulkhead.

Repairs after Serious Crashes.—So long as either the deck or the keel of the floats remains straight and the whole structure has not been logged and buckled, repairs in the field can generally be made as described in the previous paragraph. A pontoon which has actually been buckled in a crash, however, is very difficult to repair without replacing it on an assembly jig, since a whole section will probably have to be removed. If the damage appears to be of such a very serious nature, it is advisable to have photographs taken from several angles and sent to the factory with as complete a description of the damage as possible, so that detailed advice can be given.

Sometimes as a result of a serious crash, or where the propeller has cut through the float owing to a strut failure, it is found that the bow of the float is hopelessly damaged whereas the rest of it is in excellent condition. In cases of this sort it is frequently practical to cut away the entire damaged portion and splice on a new section supplied from the factory.

Repair of Struts.—In the case of crack-ups where struts and spreader tubes have been damaged, the struts themselves can generally be repaired by welding on reinforced sleeves or patches of ordinary aircraft sheet steel or tubing, but it is important to be sure that repaired struts are oiled inside, drained, and hermetically sealed so as to prevent internal corrosion. The spreader tubes, however, are generally made of *dural* or *chrome-molybdenum-steel* tubing which has been subjected to heat treatment, and in a number of cases certain struts have been designed in the same manner. *Obviously, such parts cannot be welded without destroying their strength, and factory replacements are generally required.* For these reasons it is advisable to secure advice from Edo or an authorized representative before attempting strut repairs.

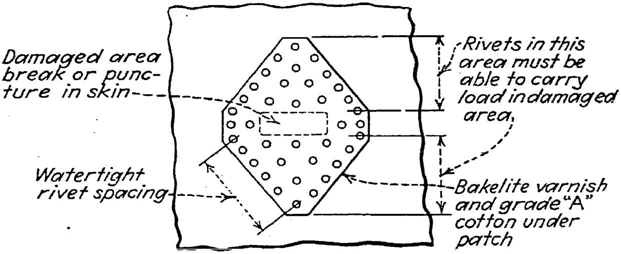
Damaged area break or puncture in skin
Watertight rivet spacing
Rivets in this area must be able to carry load in damaged area
Bakelite varnish and grade "A" cotton under patch

FIG. 192.—Repair of damaged skin in floatation compartment (Martin recommendation).

The following paragraph on repair of damaged skin in flotation compartment is as recommended in "General Repair of Stressed Skin Structures," The Glenn L. Martin Co. (see Fig. 192).

Damaged skin in this compartment is repaired in the same manner as previously discussed for (see Job Unit 27) smooth-skin repairs (see Job Unit 26) and corrugated-skin repairs. Besides being strong enough to carry the necessary load, patches in this compartment must also act as seals. This is done by putting sealing compound under the patch and using a watertight rivet spacing around the edge of the patch.

AUTHORS' NOTE: This, as the student will note, pertains to the very large type of floats.

Job Unit 43. Repair of a Torque Tube

Airplane Part.—Torque tubes for ailerons, rudders, and elevators. The tubes may be round, or they may be the nose section as shown in Fig. 194.

Estimate of Strength Required.—The stress, of course, is shear. The maximum allowable which can be developed is not over 35,000 lb. per square inch. In general, the allowable stress is much lower than this because the tube will buckle at a lower stress.

Example.—Refer to Fig. 193. Assume the tube is to be spliced. This is the severest case in repair.

Assume aluminum-alloy-tube wall 0.051 in. thick. Assume the outside diameter of tube to be 4 in.

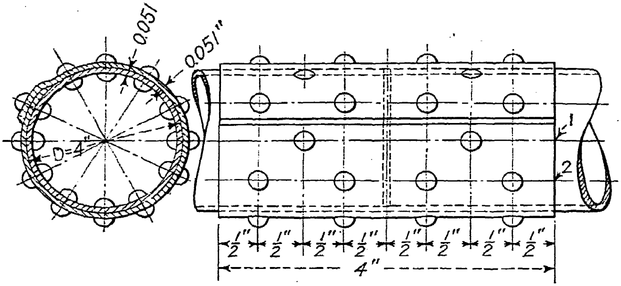

FIG. 193.—Repair splice in torque tube.

The area of cross-section of metal cut is $4\pi \times 0.051$ in. = 0.64 sq. in. Total shear to be transmitted by rivets = 0.64 sq. in. × 35,000 = 22,400 lb. Rivets required (see Table XX) = 22,400/575 = 39 rivets.

Head rivets in staggered rows are as noted in Fig. 193: 3 rows of 13 rivets per row. The pitch of the rivets (around the outer circumference of the repair plate) is determined as follows:

$$\text{Pitch} = \frac{\pi[4 + (2 \times 0.051)]}{13} = \frac{12.9}{13} = 0.992 \text{ in.}$$

To make the repair, construct a jig to hold the two ends of the tube in position while the repair is being made. The reinforcement should be cut to size and pre-formed. Rivet row 1 first, then row 2, row 3, etc.

In riveting, the rivets may be pushed in from the outside against a bucking bar, as shown in Fig. 157. Head the rivet with an air hammer placed against the head of the rivet. The operator should keep the bucking bar well up against the rivet, but he should be careful that the rivet head is not forced away from the metal.

The repair should not be too long, in this case, nor should the rows of rivets be too far apart, as the elasticity of the tubes allows them to twist slightly, thereby developing a tendency to throw the entire load on the outer rows of rivets. The closer together the rows of rivets are, the less is this effect. However, if the rows are too close, too much area in a small space will be cut away in drilling the rivet holes, thus weakening the section.

The repair of the tube in Fig. 194 is accomplished in the same manner as described above.

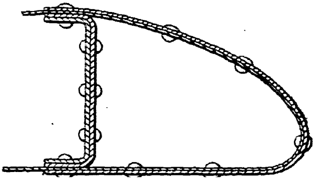

FIG. 194. Repair of leading edge.

Job Unit 44. Repair of Ribs

Airplane Part.—Ribs of wings, stabilizers, fins, and control surfaces.

Method of Repair.—Ribs are generally repaired by replacing the damaged sections. The original rib serves as a pattern in this case.

If splices are to be made, the technique used in the repair of struts (Job Unit 28) or in the repair of stringers (Job Unit 30) should be used. Diagonal bracing in the ribs are struts, and the chord members of the ribs correspond to stringers.

Job Unit 45. Repair of Semimonocoque Engine Nacelle

In general, the repairs given in job units for *fuselages* will also apply to such engine nacelles.

Job Unit 46. Repair of Dent in a Steel Tubular Strut

Example.[1]—Refer to Figs. 93, 94, 95, and 171. Occasion sometimes arises for repair or replacement of a damaged tubular member in a steel structure.

Practically all steel tubing used for structural purposes in aircraft is of chrome-molybdenum material (S. A. E. 4130) and is most often in the normalized condition (95,000 tensile strength). Some members, however, are designed for higher physical properties and require special heat treatment before assembly in the structure, for example, fuselage members receiving high-compression loads from landing gear, wing cell, etc. *Welding temperatures destroy these high properties locally in cases where welding is done after heat treatment.* If the higher properties are required for greater column strength, local heating near the ends, as in welding at the fittings, may be done without adversely affecting the column strength.

Before attempting a field repair which involves welding of an existing structure, a careful study should be made, preferably by engineering personnel, of the drawings and loads carried by the member to insure that proper consideration is given such matters.

If such a study disclosed that no special properties are required, small dents and damaged parts may be repaired, reinforced, or replaced, as indicated in Figs. 93 to 96.

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[1] As given in "Maintenance Instructions, Shrike Design 60A," The Curtiss Aeroplane and Motor Company, Inc.

Review Questions

1. State the general requirements to be met in the repair of a metal airplane structure.

2. How does a repair of a highly stressed member of a structure differ from the repair of a nonstressed member?

3. Make a list of the tools necessary in the repair of an aluminum-alloy structure.

4. How is an automatic air hammer used in heading a rivet?

5. Explain how to remove rivets in making repairs.

6. Explain how to prepare a damaged section for a reinforcement plate.

7. Discuss three ways of obtaining the load which must be carried by the repair of a highly stressed member.

8. Why is a stress analysis made in the shop not reliable?

9. What allowable shear stress may be safely assumed for aluminum alloys?

10. How may a strut be repaired?

References

1. YOUNGER, J. E., "Mechanics of Aircraft Structures," McGraw-Hill Book Company, Inc., New York, 1942.

2. "General Repair of Stressed Skin Structures," Engineering Report 432 (prepared by M. Maxfield), The Glenn L. Martin Co., Baltimore, Md. (NOTE: The entire report is reproduced, by permission, in Job Units of chap. XII.)

3. "Service Manual," Edo Aircraft Corporation, College Point, Long Island, N. Y.

4. "Erection and Maintenance Instructions, Shrike Design 60A," The Curtiss Aeroplane and Motor Company, Inc., Buffalo, N. Y.

5. Handbook of Instructions for the Maintenance of the Model DC3-178 Airplane," Douglas Aircraft Co., Inc., Santa Monica, Calif.

6. "Maintenance and Service Manual Boeing Model 247," Boeing Airplane Company, Seattle, Wash.

Questions for Thought and Study of References

1. Prepare a job unit for the repair of a Z-section stringer in a semimonocoque wing.

2. In semimonocoque fuselage construction, are the bulkhead rings generally cut out for the stringers to pass through, or are the stringers generally cut out for the bulkhead rings to pass through? Why?

3. Suppose it is necessary to cut a small door in the side of a fuselage, thereby cutting a stringer, how would you reinforce the door frame to carry the load?

Outline a static test to prove the strength of your design. (NOTE: This change of structure would require the approval of the Department of Commerce.)

CHAPTER XIII

REPAIR OF WOOD, WIRE, AND FABRIC STRUCTURES

Many of the small airplanes are still made of wood, wire, and fabric, and the control surfaces of some of the modern transports have fabric surfaces for lightness in the prevention of fluttering. Woodworking is also important in metal construction, since the forms for shaping the metal are made of wood.

207. Woods in Aircraft Construction.—The principal woods used are:

a. *Spruce.*—Light, high strength, fair stiffness, fairly tough, easily worked, and is generally free from hidden defects. Used for ribs, etc.

b. *Douglas Fir.*—About like spruce, but a little heavier, and is more liable to check, crack, or split.

c. *Ash.*—About 50 per cent heavier than spruce, strong, tough and very straight-grained. Bends well when steamed. Used for bent work.

d. *White Pine.*—Less stiff, softer, and less tough than spruce, quite uniform in structure, with few hidden defects. Easy to work; glues well.

e. *Birch.*—Classified as hardwood, very tough and resistant to wear, has uniform grain and takes fine finish, heavy. Used generally in making plywood.

See Table XXII for other properties of these aircraft woods.

TABLE XXII.—PROPERTIES OF AIRCRAFT WOODS

Material	Specific gravity when dry		Weight, lb. per cu. ft.; moisture content at 15 per cent	Modulus of rupture, maximum stress in fibers at breaking point, lb. per sq. in.	Modulus of elasticity, lb.-in., units	Shearing strength parallel to grain, lb. per sq. in.
	Average	Minimum				
Spruce	0.40	0.36	27	9,400	1,300,000	750
Douglas fir	0.51	0.45	34	11,500	1,700,000	810
Ash	0.62	0.56	41	14,800	1,460,000	1,380
White pine	0.42	0.38	27	9,300	1,310,000	640
Birch	0.68	0.58	44	15,500	1,780,000	1,300

208. Characteristics of Wood.—The usefulness of woods is affected by the following factors:

1. *Method of Sawing.*—Plain sawing which produces flat-grained lumber, and quarter sawing which produces edge-grained lumber. In the first case the lumber warps less and does not split and crack so badly. In the second case, it is cheaper to cut, and if knots are present, they are round instead of spiked.
2. *Composition.*—Cellular honeycombed structure, has hard annular rings called summerwood and soft annular rings called springwood. Too much springwood causes brittleness. The strength is approximately proportional to the weights of similar pieces, that is, to the specific gravity.
3. *Moisture Content.*—The moisture content should be about 15 per cent.
4. *Diagonal and Spiral Grain.*—The limit of this type of grain is a 1-in. deviation in 15 in.
5. *Compression Failures.*—These may have been caused by a storm bending the tree, or by a high stress in the falling of the tree. Look for hairlines across the grain of the wood.

209. Glues and Gluing.—Casein glue is used in aircraft construction and in making molds for forming thin-sheet-metal structures.

Casein glue is composed of casein (the curd of milk, washed and dried), lime, and water. It comes in two forms: (1) In dry form, ready to be added to water; and (2) in the form of the various ingredients to be combined at the time of mixing with water. The first is *prepared glue,* and the second is *wet-mix* glue.

In mixing the glue, a *mechanical mixer* is generally used, but it can be mixed satisfactorily with a paddle. The glue should be poured *slowly* into the water while the mixture is being stirred. Care should be taken that lumps do not form. When the powder is thoroughly mixed in water, it should be *allowed to set for* 15 *to* 20 *min.* for the proper chemical action to take place, and then again stirred for about 5 min.

The glue is spread with a brush. The spread should be thick enough to make the film continuous and to insure that the glue has penetrated the cells of the wood.

The wood to be glued should be dry. The surfaces of contact should be planed smooth, and all sawdust particles removed. The surface of contact should first be washed in a solution of the glue made thin with a glue-to-water ratio of 1 to 3. *This is called sizing.*

Pressure is applied to the joints by nails or special clamps. If no glue is pressed out in the clamps, the joint is said to be *chilled* or *dried*. If the glue is mostly squeezed out of the joint, it is said to be a *starved* joint.

Splicing.—This is usually accomplished by beveling the ends of the members to be spliced, at the same angle, and gluing the beveled surfaces. This is called a *scarf joint*. A 1 to 10 slope is satisfactory for plain wood, and 1 to 20 or more for plywood. The beveling may be readily accomplished by the use of a jointer. Guide blocks, with the proper 1 to 10 or 1 to 20 slope, should be used to give the material the proper angle with reference to the cutter of the joints.

210. Airplane Fabrics.—Two kinds of fabric are popular in aircraft use, *linen* and *cotton*. A high grade of cotton fabric is generally used in this country. It is specified as *grade A*. The weight per square yard is 4 to 4.5 oz. and its strength is about 80 lb. per inch width.

The principal requirements of a fabric surface are as follows:

1. The fabric should be securely attached to withstand the heavy loads it is required to carry.
2. The fabric should follow smoothly the contour of the surface. It should not sag between the supporting ribs.
3. The surface should be smooth and taut.
4. Provision should be made for inspection.
5. Holes for drainage of water should be provided. For this purpose grommets are inserted in the fabric.

211. Equipment Required in Fabric Work.

1. Airplane-fabric *sewing thread*, size 16/4 to 20/4 for machine sewing, and 25/3 to 30/3 for hand sewing.
2. *Cord* for sewing fabric to wing ribs, approximate strength 40 lb.
3. *Beeswax* to coat the rib cord to prevent fraying. Oil for this purpose will ruin the doped finish.
4. *Dopeproof paint* for applying to wood and metal surfaces which come in contact with doped surfaces.
5. *Long rib-cord needle* (10 to 16 in.), long enough for sewing fabric to wing ring.
6. *Curved needles* for making stitches in a tightly stretched fabric.
7. *Reinforcing tape* which is placed under all cord lacing to prevent the cord from tearing out through the fabric; ½ to ¾ in. wide.
8. *Finishing tape* for covering reinforcing tape and other surface imperfections.

9. *Drainage grommets* to be placed in low spots to allow drainage of moisture collected internally.

10. *Tacks* for permanent and temporary use. Monel-metal, tinned-iron, or brass tacks are best, as they do not corrode.

212. Seams, Stitches, and Knots.—Figure 195 shows the types of seams generally used; they are the *plain overlap*, the *French fell*, the *folded fell*, and the *English fell* seams.

The seine knot is generally used to lace cloth to ribs. This knot is shown in Fig. 196.

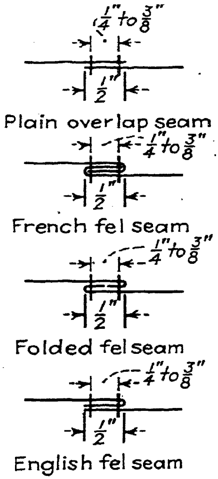

FIG. 195.—Airplane fabric seams.

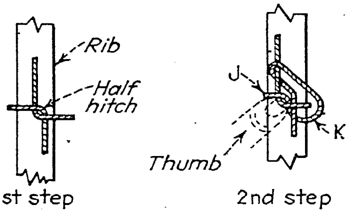

FIG. 196.—Seine knot. Hold tension in *J* until loop *K* is tightened.

The cord is laced entirely around the rib, thus binding both the upper and lower surfaces of the fabric, unless provision is specifically made for lacing otherwise (see Fig. 197).

213. Additional Information.—If much fabric work is to be done, the student should refer to "Airplane Construction and Repair," by J. E. Younger, McGraw-Hill Book Company, Inc., Chap. IX, or to U. S. Army Specifications, No. 98-24108-H, Jan. 18, 1930, or later specification, if published. See also Job Unit 47.

214. Doping Fabric Surfaces.—The following rules are generally followed in doping fabric surfaces:

1. *Kinds of Dope.*—*Acetate* and *nitrate.* The latter is generally used because it has better tightening qualities. *It is Inflammable.*

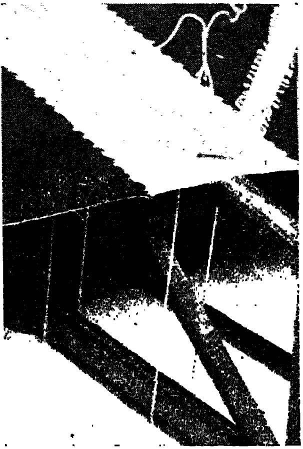

FIG. 197.—Rib lacing.

2. *Purpose.*—To give *tautness* to fabric, to provide a *smooth surface*, and to add *strength* to the fabric. The *pigmented dope* protects the clear dope from the destructive rays of the sun.

3. *First Step.*—Lay the work to be doped on a flat surface so that the dope will not run. Apply a light coat of clear dope with a 5-in. brush; apply quickly without repeating strokes. Allow to dry; time, about 3 hr. in 70° to 80°F. dry room air.

4. *Second Step.*—Binding tape and grommets or *breathers:* cut strips of 2¼- or 2½-in. tape long enough to run from trailing edge, over the top surface of the wing around the entering edge and back to the trailing edge to cover each rib, including butt rib. Cut a strip to run from the entering edge to the butt rib along entering edge around the tip to the trailing edge, and another strip to run from the trailing edge of the butt rib to the trailing edge of the tip along the trailing edge of the surface. Tack the center of the strips to be placed over each rib to the entering edge of each rib, roll the two ends up, and clip with a clothes pin, one end being tacked to trailing edge of the butt rib.

From a piece of fabric which has previously been tacked on a frame—which has been given one coat of dope and allowed to dry—cut a sufficient number of circular pieces 1¾ in. in diameter so that one piece will be available to go on the surface 1 in. from the trailing edge on the under side between each rib. With a *shoemaker's eyelet* set insert a small shoe eyelet in the center of each circular piece of fabric. These are for the breather holes. A punch to cut out these circular pieces can be made by sharpening the end of a piece of 1¾-in. pipe.

5. *Third Step.*—Second and third coats of dope. If the surface is sufficiently dry by this time, the second coat of clear dope can be brushed on, starting at one end and doping the binder and breather patches on as their location is reached. An experienced doper can dope the binder on between the first and second coats by using a brush the same width as the binder and by not allowing the dope that he puts the binder on with to smear the area on either side of the binder. This eliminates the flat appearance of the binder noticed on so many wings, for by doing this the binder has the same number of coats of dope as the rest of the fabric. The better method for the beginners is to put all binders and reinforcing patches on with the second coat of dope. When the second coat of dope is dry and the fabric has tightened all it will, the third coat of clear dope is brushed on. Each coat of dope after the second coat should be sanded lightly with No. 320 or No. 240 water sandpaper.

6. *Fourth Step.*—Applying pigmented coats. The next two coats being aluminum-pigmented, the pigment should now be mixed with the clear dope. The best method to determine the amount of pigment being put into the dope is to sift the pigment in slowly, stirring thoroughly and testing from time to time for color by dipping a clean piece of wood into the dope. When the density of color desired is noted on the stick, stop stirring pigment into dope.

The *pigmented dope* is applied exactly the same as the coats of clear dope were applied, allowing a sufficient length of time between coats for the dope to dry and for the fabric to tighten. Very often flat or chalky-looking streaks will be noted on the doped surface. These are called *blushes* and are caused by dampness in the air. They can be removed by spraying with *dope thinner* or by wiping the blushed places slightly with a rag soaked with thinner or blush reducer.

Doping should not be attempted in rainy weather unless the air in the doping room has been dried artificially. For the health of the worker, good ventilation, lighting, and heating in the dope room are essential.

The *aluminum pigment* is used in this case to form a base for the colored lacquer. Aluminum, when used as a base, cuts down the quantity of lacquer necessary to bring the work up to the color desired and also forms about the smoothest base obtainable.

7. *Fifth Step.* Lacquer spraying. The lacquer is mixed generally in the proportion of 50 per cent lacquer to 50 per cent lacquer reducer. This mixture is put into a quart container attached to a *spray gun.* The surface to be sprayed is stood up on edge on a pair of easels. The operator stands in front of the work and, starting at one end, sprays the work from the *top edge to the bottom edge then from the bottom edge to the top edge,* overlapping each stroke sufficiently to give an evenly coated appearance to the surface. The spray gun should be held about 10 in. from the work, and the stroke should be at an even speed at all times. *Slowing up of the stroke will cause the lacquer to pile up and run.* It is a good idea to practice with an empty gun or one filled with water until the arm is trained to carry an even stroke and to open and close the gun automatically at the top and bottom of the stroke, before attempting to shoot lacquer.

The air pressures to be carried on the gun depend a great deal on the density of the material being used and the speed and position of the operator. These will be learned with practice.

JOB UNITS

Job Unit 47. Fabric Patching

Outline of Work.—Two types of fabric patches are to be made, one for a *puncture* of the surface and one for an *L-shaped tear* in the fabric.

Tools and Materials Required.—Sharp knife, pinking tool, shears, curved needle, No. 20, four-cord cotton thread, airplane fabric, clear dope, brush, wiping rag. Compasses and scale will be of use in making a neat job.

Discussion.—Damage to an airplane fabric usually occurs in one of two forms: (1) puncture, or (2) a tear.

1. A puncture is usually not more than 1 in. in largest dimension. It is often cross-shaped with small ears or tabs of loose fabric inside the hole.

2. A tear in the fabric is usually L-shaped or V-shaped.

In either case, punctured or torn, if the maximum dimension of the repair is not greater than 1 in., no sewing is necessary; and the repair is made by cutting away the loose flaps until a clean, round hole is obtained in the fabric; then the hole is covered with a circular patch having *pinked* edges.

If the puncture or tear is greater than 1 in. in dimension, the flap should be closed with a baseball stitch.

When the sewing has been accomplished, a square patch is cut large enough and then pinked and doped on so that the full original strength of the area affected by the tear is realized.

The patches should have five coats of clear dope applied at intervals of at least 2 hr. The patch should be sanded lightly between the last two coats. When sanding, be careful not to cut through the fabric on the high spots made by the stitches.

In a shop where a great deal of patching is done, a roll of fabric specially prepared for repair work, is kept on hand. In the preparation of this material it is first stretched on a frame, and given five coats of dope, then cut and rolled for future use. Having this repair material on hand shortens the patching process time considerably, as only two coats of dope are needed, with one sanding between, to make a perfect patch.

Doping should not be attempted unless the temperature is 70°F., or above, and the air is dry and still. Drafts, moisture, and cold air will cause the dope to blush. If an emergency patch must be made under adverse conditions, mix retarder with the dope in the proportion of a teaspoonful or thereabouts to a quart of dope.

Procedure.—The instructor will indicate and assign certain repair patching. Trim the punctures and sew the tears. Lay out patches that will overlap about 2 in. The minimum allowable lap is 1½ in. Cut all patches about ½ in. oversize, and trim down to size with the pinking tool.

Prepare the surface for patching by soaking with dope and then wiping clean. Be careful not to allow dope to run through the tear, as it will drip and disfigure the opposite fabric surface. Soak the patch with dope, apply it to the surface, adjust it so that it is square with the tear and on center, press all bubbles and wrinkles out from under the patch with the fingers, and then brush the patch on smoothly. Use plenty of dope, and do not brush too long or the surface will become tacky, and smear. Allow 2 hr. for drying after each application before applying the next coat.

215. Aircraft Wires.—Many uses for aircraft wires are found even in the latest type of airplane construction. For example, there is nearly half a mile of control cable in the Boeing B-17 (four-motored bomber), with a corresponding number of *terminal splices* and *terminals*.

For its size and weight, aircraft wire has very great strength.

216. Hard Wire.—This type of wire, a single strand, is also known as solid aviator wire and tinned aircraft wire. It is used mostly for drag wires. Table XXIII gives useful data on hard wire.

217. Aircraft Ferrules.—Aircraft ferrules are used in making terminals for hard wire. See Table XXIV for characteristics.

218. 7 by 7 Aircraft Cord.—This cord is composed of seven strands of wire spiraled into the form of a rope. Each of the strands is composed of seven hard wires coated with a rust preventative; cords less than ⅛ in. diameter are mostly used. See Table XXV for characteristics.

Table XXIII.—Tinned Aircraft Wire (Hard Wire)

Steel-wire gauge	Diameter, in.	Weight per 100 ft., lb.	Torsion test, number of turns in 8 in. (minimum)	Bend test number of bends (minimum)	Breaking strength, lb. (minimum)	Tensile strength, lb. per sq. in. (minimum)
0	0.306	24.87	3	2	14,000	190,000
1	0.283	21.14	4	2	12,000	192,000
2	0.262	18.25	5	2	10,520	195,000
3	0.244	15.71	5	2	9,200	197,000
4	0.225	13.36	6	3	7,950	200,000
5	0.207	11.31	8	3	6,850	204,000
6	0.192	9.73	9	4	6,030	208,000
7	0.177	8.27	9	4	5,250	213,000
8	0.162	6.93	11	5	4,520	219,000
9	0.148	5.78	12	6	3,850	224,000
10	0.135	4.81	15	7	3,290	230,000
11	0.120	3.80	17	9	2,670	236,000
12	0.105	2.91	21	11	2,090	241,000
13	0.091	2.23	25	14	1,600	248,000
14	0.080	1.69	29	17	1,260	252,000
15	0.072	1.37	33	21	1,040	255,000
16	0.062	1.05	38	25	775	258,000
17	0.054	0.770	46	31	600	263,000
18	0.047	0.583	53	39	460	268,000
19	0.041	0.444	63	50	356	270,000
20	0.034	0.323	74	78	250	275,000
21	0.032	0.270	84	85	225	280,000

219. 7 by 19 Aircraft Cord.—This wire is composed of seven strands, each strand of which is composed of 19 hard wires. See Table XXVI for characteristics.

220. Preformed Cable.—The strands of this type of cable are preformed to the configuration they will have in the cable. This

TABLE XXIV.—AIRCRAFT FERRULES—8 WIND

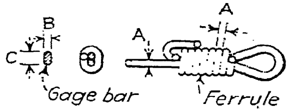

FIG. 198.

Gage bars shall pass through ferrules with a clearance of approximately 0.003 in. See Fig. 198 for dimensions.

Size, Roebling or steel-wire gage		Gage bar		Approx. weight, lb. per 1000 pieces
No.	*A*, in.	*B*, in.	*C*, in.	
8	0.162	0.164	0.328	67.00
9	0.148	0.150	0.300	53.42
10	0.135	0.137	0.274	38.61
11	0.120	0.122	0.244	26.13
12	0.105	0.107	0.214	18.76
13	0.092	0.094	0.188	12.50
14	0.080	0.082	0.164	8.56
15	0.072	0.074	0.148	6.50
16	0.063	0.065	0.130	4.25
17	0.054	0.056	0.112	2.76
18	0.047	0.049	0.098	1.68
19	0.041	0.043	0.086	1.14
20	0.035	0.037	0.074	0.83
21	0.032	0.034	0.068	0.52

TABLE XXV.—7 BY 7 (WIRE CENTER) GALVANIZED AIRCRAFT CORD
(Used below 1/8 In. Mostly)

Diameter of cord, in.	Breaking strength of cord, lb.	Approximate weight, lb. per 100 ft.
5/32	2600	4.67
1/8	1350	2.45
7/64	970	1.75
3/32	920	1.45
1/16	550	.93
5/64	485	.81

relieves the initial strain in the wire due to bending and twisting. This type of cable will not flare out when it is cut. A trade name of this type of cable is Tru-Lay. See Table XXVII for characteristics.

TABLE XXVI.—7 BY 19 TINNED AIRCRAFT CORD

Diameter of cord, in.	Breaking strength of cord, lb.	Approximate weight, lb. per 100 ft.
1/2	24,400	43.20
7/16	19,000	34.00
3/8	14,400	26.45
11/32	12,500	22.53
5/16	9,800	17.71
9/32	8,000	14.56
1/4	7,000	12.00
7/32	5,600	9.50
3/16	4,200	6.47
5/32	2,800	4.44
1/8	2,000	2.88

TABLE XXVII.—TABLE OF TRU-LAY AIRCRAFT CABLE SIZES, WEIGHTS, AND STRENGTH

Size	Weight per 100 ft.	Breaking strength
1/16 7 × 7	0.81 lb.	485 lb.
3/32 7 × 7	1.45 lb.	920 lb.
1/8 7 × 7	2.45 lb.	1,350 lb.
1/8 7 × 19	2.88 lb.	2,000 lb.
5/32 7 × 19	4.44 lb.	2,800 lb.
3/16 7 × 19	6.47 lb.	4,200 lb.
7/32 7 × 19	9.50 lb.	5,600 lb.
1/4 7 × 19	12.00 lb.	7,000 lb.
5/16 7 × 19	17.71 lb.	9,800 lb.
3/8 7 × 19	26.45 lb.	14,400 lb.

221. Aircraft Thimbles.—These are used in the terminals of cables to prevent undue wear and bending on the cable. See Table XXVIII for dimensions.

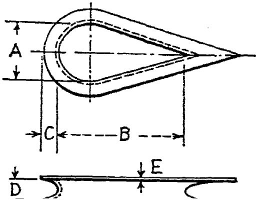

FIG. 199.—Dimensions of aircraft thimbles.

TABLE XXVIII.—AIRCRAFT THIMBLES (SEE FIG. 199)

Size	Inches					Approx. weight, lb. per 1000 pieces
	A	*B*	*C*	*D*	*E*	
1/16 and 3/32	0.35	0.70	0.07	.09	0.032	3.00
1/8	0.35	0.70	0.07	.13	0.032	4.31
5/32	0.40	0.80	0.10	.17	0.032	6.50
3/16	0.50	1.00	0.135	.21	0.032	9.00
7/32	0.60	1.20	0.15	.24	0.032	14.31
1/4	0.70	1.40	0.17	.25	0.032	16.31
9/32	0.80	1.60	0.198	.30	0.040	26.25
5/16	0.90	1.80	0.21	.33	0.040	29.50
3/8	1.00	2.00	0.26	.39	0.060	77.00
7/16	1 1/8	2 1/4	0.33	.46	0.080	122.00
1/2	1 1/4	2 1/2	0.40	.52	0.080	167.00

222. Tru-Loc Terminal Fittings.—Figure 200 shows such a fitting. The fitting is pressed over the cable by a special machine. Tests have shown that the fitting will develop the full strength of the cable. (See report by American Cable Company.)

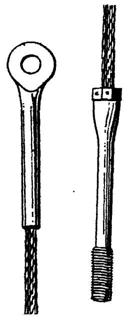

FIG. 200.—Tru-Loc terminal fittings.

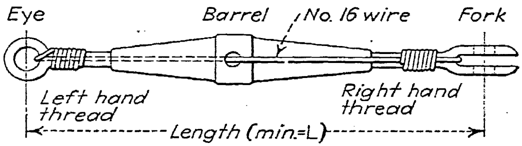

FIG. 201.—Turnbuckle assembly.

223. Aircraft Turnbuckles, Shackles, and Clevis Pins.—Figure 201 shows a turnbuckle assembly, and method of locking turnbuckle. Table XXIX gives the strength and take-up of standard turnbuckles.

TABLE XXIX.—STRENGTH AND TAKE-UP OF AN STANDARD TURNBUCKLES

Length L, in.	Strength, lb.	Take-up, in.	Length L, in.	Strength, lb.	Take-up, in.
4.5	800	1.260	8	1600	2.625
4.5	1600	1.040	8	2100	2.500
4.5	2100	0.875	8	3200	2.250
4.5	3200	0.620	8	4600	2.125
4.5	4600	0.375	8	6100	1.625

TABLE XXX.—SIZE OF SHACKLES AND CLEVIS PINS FOR CABLE STRENGTH AN STANDARD

Cable Strength, Lb.	Clevis-pin Size, In. Diameter
800	3/16
1600	3/16
2100	3/16
3200	1/4
4600	5.16

JOB UNITS

Job Unit 48. Loop Terminals in High-carbon Tinned Aircraft Wire

Outline of Work.—Make a sample drag wire with loop and turnbuckle on one end and loop only on the other end, measuring 18 in. from center of turnbuckle fork to outer bearing face of loop. Threads on turnbuckle must be flush with end of barrel, when measurement is made.

Tools and Materials Required.—Bending jig, three-square file, heavy pliers, bench vise, No. 12 aircraft wire, No. 12 ferrules, 8-in. turnbuckle.

Discussion.—Repair shops with a large variety of equipment usually have on hand a wire-bending jig operated by a lever. However, very often the mechanic finds it necessary to make hard-wire loops without any such special tools. The purpose of this work is to give the student practical experience in handling such a situation with the least possible amount of ready-made equipment.

The jig (Fig. 202) which we will use for hand bending is made from two bolts, minus the heads, 5/16 in. and 3/8 in., respectively, in diameter, welded into a fork which tapers to a gap of about 1/8 in. When set up in a vise, this fixture is all that is needed to make perfect bends in any size of hard wire from 10 to 14 gauge. Of course, a little more experience is necessary than with the use of a mechanical jig, but by making a few experimental bends, the student will soon become capable of producing an acceptable job. It is a good idea to make a few practice loops before attempting the finished sample which is to be turned in for inspection.

Procedure

1. Cut wire about 16 in. long; clamp bending jig in vise and place the wire in the fork of the jig. See Figs. 202*a*, 202*b*, and 202*c*.
2. Bend short end to left, as in Fig. 202*b*.
3. Bend long end to left, as in Fig. 202*e*.
4. Take loop off of post and place short end in fork, as in Fig. 202*f*.

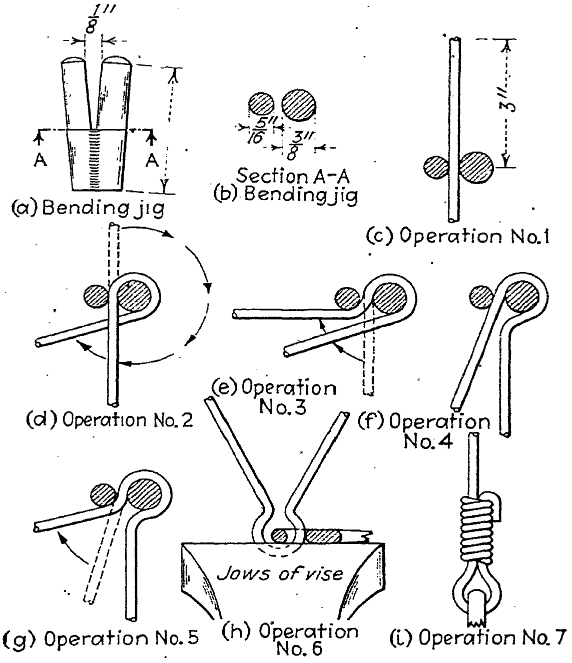

FIG. 202.—Making a terminal in hard wire.

5. Bend short end to left, as in Fig. 202*g*.
6. Take fork out of vise, put jaw guards on vise, and clamp loop with turnbuckle in place, as in Fig. 202*h*.
7. Slip ferrule over both wires and press down against loop. Bend short end down against ferrule, as in Fig. 202*i*.

NOTE: Slip second ferrule on long wire at once. If you do not put it on now, you are likely to start your bend on the other end of the wire, and then find that the ferrule is missing. If this mistake is made, the job must be rejected for the reason that high-carbon wire can not be straightened and rebent without straining so that it will be unreliable in service.

Now measure out 18 in. from the center of the turnbuckle fork, marking the 18-in. point on the wire with a pencil. This is the length to which the drag member should be made. However, bend allowance must be taken into consideration. By trial and error it has been found that a bend allowance of about 5/18 in. is correct for 12-gauge wire when the loop is bent on a 3/8-in. post. Therefore, from the 18-in. mark measure back 5/16 in. toward the first loop and mark that point with a pencil. Set this last mark directly between the posts of the bending fork and proceed as before.

If the bends are properly made, it will be found that the finished wire is a trifle overlength, perhaps 1/16 in. longer than 18 in. This is desirable, rather than to have the wire undersize, for the reason that such wires are almost always used with turnbuckles; and it is obviously better to run the threads a little further into the barrel than to have a few threads left outside of the barrel.

Note that the hard wire must not be scratched, nicked, or marred in any way. The material is carbon steel of high temper, and any damage on the surface is likely to start a fracture under stress. Always use soft-metal guards on the vise jaws when gripping the wire.

Do not attempt to make the ferrules by hand. They are wound by machinery and are carried in stock by all aircraft-supply stores.

When you have finished a sample which you think you cannot improve, tag it with your name and hand in.

Job Unit 49. Soldered Cable Terminal

Work Required.—Sample cable terminal made from 1/8-in. 7 by 19 aircraft cable about 24 in. long.

Tools and Materials

1. Soldering outfit.
2. Side-cutting pliers.
3. Bench vise.
4. Bench shears, or cold chisel, for cutting taper on end of cable.
5. A 24-in. length (approximately) of 1/8-in. 7 by 19 aircraft cable.
6. 1/8-in. aircraft thimble.
7. 8 ft. of No. 20 B. & S. soft brass or copper wire.

Discussion.—Soldered cable terminals have been extensively used for the attachment of both rigging wires and control cables. On modern planes, these uses are largely replaced by streamlined tie rods for rigging, splices for the control cables. Nevertheless, it is necessary to be familiar with the proper method of making soldered terminals, both for emergency repairs and in the repair and maintenance of the older types of aircraft.

When properly made, the soldered terminal is equal in strength to a navy splice. However, external appearances are sometimes deceptive. Also, the heat and flux are likely to impair the physical qualities of the fine hard-drawn strands from which the cable is made. Furthermore, the extreme cold of high altitudes changes the physical properties of tin, causing a reduction in the holding power of the solder. Last, but not least, a soldered terminal weighs at least three times as much as a navy splice, and a number of them will add pounds to the structural weight of the aircraft. Therefore, from any viewpoint, with the possible exception of first cost, the navy splice is to be preferred.

Procedure

1. Cut a piece of ⅛-in. 7 by 19 cable, about 24 in. long, taking care either to bind or to solder both sides of the cut before using shears. One end of cable should be soldered solid so it can be cut on the bias for tapering.
2. Cut the end of the cable to a taper of about 30 deg. (see Fig. 203).

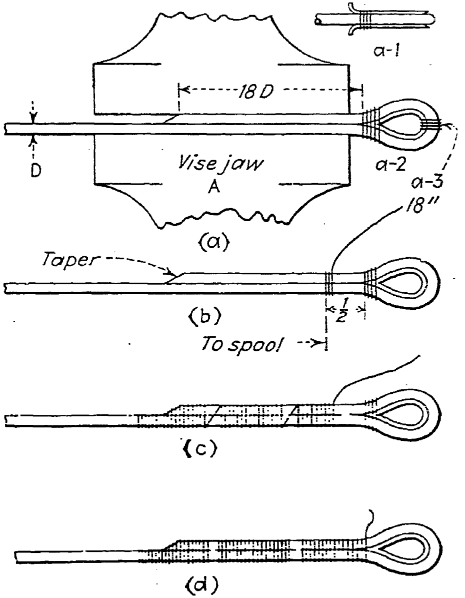

FIG. 203.—Soldered cable terminal.

3. Bend thimble points out 45 deg. [See Fig. 203(*a*-1).]
4. Bend cable around thimble, leaving free end of a length equal to at least 18 times the diameter of the cable. Clamp in vise as in Fig. 203*a*.
5. Wind the No. 20 wire on a short piece of hose, or on a block of soft wire, for use as a spool in handling the winding.
6. Using the No. 20 wire, wrap cable tightly for two or three turns above the thimble points, as in Fig. 203(*a*-2). This is only to hold cable on thimble while making the terminal. It is to be removed before any soldering is done. Also wrap as in Fig. 203(*a*-3). Clamp thimble and loop in vise so cable below thimble will be free for wrapping.
7. Start the main wrap as in Fig. 203*b*, about ½ in. below thimble points, leaving about 18 in. of free wire for finishing. Wrap close and tight for about ½ in., moving away from thimble. Leave a ⅛-in. gap and continue

the close wrapping down over the taper to about ¼ in. beyond the point where the taper ends. Cut off the wire and press the end down, as in Fig. 203*c*.

8. Go back to 18 in. free end of wire, and wrap toward thimble. When wire is up against thimble throat and under points as in Fig. 203*d*, bend points down over wrapping and cut wire off close to thimble.

9. Soak entire terminal in very hot solder, using plenty of flux. Use the paste type of flux, which is noncorrosive. Acid flux must never be used around aircraft.

10. Allow solder to cool until almost pasty. Load joint with solder and then wipe off terminal quickly with a rag. The solder should be a solid mass throughout all the wrapping and in the gaps. Straighten in vise.

11. If the last operation is done quickly and at the right time, a smooth, solid joint will be the result.

Job Unit 50. The Navy Splice

Outline of Work.—Two splices are to be made in the ends of a piece of ⅛-in. 7 by 19 cable about 24 in. long. The first splice is to be made with the help of the instructor, if necessary. The second splice is to be made alone, and handed in for grading.

Nomenclature

1. *Standing cable:* That part of the cable which is to be put in service after the splice is finished.
2. *Free end:* The loose end of the cable, about 8 in. long, which is to be spliced into the standing cable.
3. *Bight:* The loop of cable which is bent around the thimble.
4. *Strand:* One of the seven small cords which form the cable as received.
5. *Core,* or *heart strand:* The single straight strand running down the center of the cable, around which the other six strands are twisted.
6. *Thimble:* The grooved metal eye around which the cable is bent for splicing.
7. *Serving:* The twine wrapping which covers the sheared ends of the splice.
8. *Marlin spike:* The hand awl which is used to lift or separate the strands.
9. *Splicing clamp:* The fixture which is used to hold the bight firmly on the thimble while the splice is being made.
10. *Tuck:* To thread a free strand through the standing cable.
11. *Round of tucks:* Completion of a series of single tucks around circumference of the cable.

Tools and Materials Required

1. Splicing clamp.
2. Heavy pliers.
3. Marlin spike.
4. Bench vise.
5. Wooden mallet.
6. Wood block for anvil.
7. Linen twine.
8. Orange shellac.

9. Piece of 7 by 19 tinned aircraft cable, ⅛ in. in diameter by 24 in. long, soldered on both ends.

10. Two ⅛-in. aircraft thimbles.

Procedure.—Bend out points of thimble about 45 deg. Make bight about 8 in. from end of cable; place thimble in bight, and grip bight in splicing clamp. Set clamp in vise, with free end of cable standing vertically on the left.

General Remarks

1. Before starting a splice, free end of cable should be sweated with solder for about 1 in. Never cut cable without soldering or binding both sides of cut.
2. A completed splice consists of five rounds of tucks.
3. After the third round is completed, the core strand is cut off close to the cable.
4. Tapering of the splice is begun in the fourth round by tucking half strands instead of full strands.
5. The taper is finished in the fifth round by tucking quarter strands instead of half strands.
6. The finished taper is covered by serving with linen twine and giving two coats of orange shellac.

Detailed Procedure

1. In the first round, all tucks are made to the right or with the twist of the cable, except the fifth tuck, which goes to the left or across the twist of the cable. (See Fig. 204.)
2. In all of the rounds following the first, all tucks are made to the left, or across the twist. (See Fig. 205.)
3. The second round, and all following rounds, are easiest to manage if the Marlin spike is inserted toward the free strand which is to be tucked.
4. To obtain a tight splice it is necessary to pull all slack out of each tuck, and then bend each strand down in place without releasing tension.
5. In all of the first three rounds, the core strand should be pulled tight and left standing straight up, and should not be bent down like the six outer strands.
6. At the end of any round, after all tucks are pulled tight, the six strands should stand out from the cable all in the same plane, like spokes from a hub. If one or more strands are left high or low, there will be an open spot in the finished splice.
7. The splice should be hammered after the second and fifth round. Use a wooden mallet and a wooden block for an anvil, hammering the splice across the twist of the cable to set the tucks.
8. After the splice is beaten smooth and tight following the fifth round, the halved and quartered strands should be sheared off close to the cable, and hammered lightly.
9. In serving the splice, start on the standing cable about ⅛ in. from the last sheared end, and wrap toward the thimble. The serving should be

stopped after all sheared ends are covered, leaving the first two rounds visible for inspection.

First round of tucks: Figure 204*a* shows a cross-section of the cable at the thimble points, before the splice is started.

Figure 204*b*: Insert spike under No. 1 and separate it by underrunning spirally and pulling spike through the soldered end. Tuck No. 1 to the right, under the three strands *B-A-F*.

Figure 204*c*: Separate No. 2 as above; tuck through same opening as No. 1, to the right under the two strands *B-A*.

Figure 204*d*: Separate No. 3 as above; tuck through same opening, to the right under the one strand *B*.

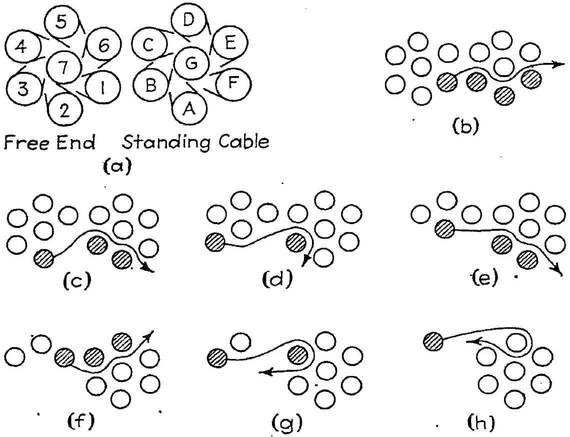

Fig. 204.—First round of tucks in the navy splice.

Figure 204*e*: Pick out core strand, No. 7, separate as above, and tuck to the right, directly on top of No. 2.

Figure 204*f*: Separate No. 6, and tuck through the same opening as before, but to the *left*, under the two strands *C-D*.

Figure 204*g*: There are two free strands remaining. Separate them and tuck No. 4 to the right under *C*. It will form a spiral around standing strand *C*.

Figure 204*h*: Tuck No. 5 to the right under *D*. It forms a spiral around standing strand *D*.

Second and third rounds of tucks: Figure 205*a* shows a cross-section of the splice after the first round of tucks has been completed. Note that the core strand, No. 7, is pressed close to the core of the standing cable. This set of sketches applies to the second and third rounds. The fourth and fifth rounds are the same, except that the core, No. 7, has been cut off.

Figure 205*b*: Insert spike under *A*; tuck No. 1 over *F* and 7, under *A*, and out; pull it back, above No. 2.

Figure 205*c*: Insert spike under *B*, tuck No. 2 over *A*, under *B*, and out; pull it back, above No. 3.

Figure 205*d*: Insert spike under *C*, tuck No. 3 over *B*, under *C* and out; pull it back, above No. 4.

Figure 205*e*: Insert spike under *D*, tuck No. 4 over *C*, under *D*, and out; pull it back, above No. 5.

Figure 205*f*: Insert spike under *E*, tuck No. 5 over *D*, under *E*, and out; pull it back, above No. 6.

Figure 205*g*: Insert spike under *F*, tuck No. 6 over *E*, under *F* and out.

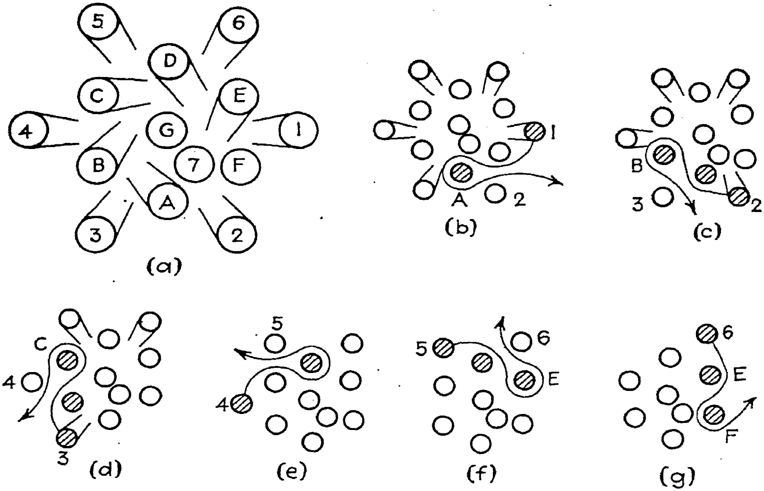

Fig. 205.—Second round of tucks in navy splice.

Job Unit 51. Roebling Splice and Test of Cable Terminals

Outline of Work

A. Make a navy-type cable splices (see Job Unit 50) at the ends of a section of aircraft control cable such that the bearing points of the thimbles will be 14 in. apart.

B. Make Roebling splices in the ends of a section of aircraft control cable as in *A*.

C. Make soldered-type cable terminals in a section of aircraft control cable as in *A*.

D. Make hard wire terminals in the ends of a section of hard wire such that the bearing points of the terminals will be 14 in. apart.

E. Test above specimens in tensile testing machine.

F. Write report covering tests, and determine effectiveness of terminals by comparison with original strength of wire. Determine margin of safety over Department of Commerce rated strength of terminals.

Tools and Material Required

a. Splicing clamp
b. Heavy pliers.
c. Marlin spike.
d. Bench vise.
e. Wooden mallet.
f. Wood block for anvil.
g. Soldering outfit.
h. Bench shear.
i. Bending jig.
j. 3-cornered file.
k. No. 12 hard aircraft wire.
l. No. 12 ferrules.
m. ⅛-in. 7 by 19 aircraft cable.
n. ⅛-in. aircraft thimbles.
o. No. 20 B. & S. soft brass or copper safety wire.
p. Linen twine.
q. Orange shellac.

Discussion.—It is the purpose of this project to give the student additional experience in making the various types of wire terminals and to let him determine, by test, the strength of the terminals that he has made. It is an extremely difficult task to make any type of joint in a tension member which will not seriously reduce the strength of the member, and for this reason terminal efficiency factors are introduced. These factors are determined by comparing the developed strength of the member (with terminal) with that of the original member. A terminal in a tension member usually causes a failure in the material adjacent to the terminal in what is known as the *affected area*. Soldered-type cable terminals are highly efficient as a terminal as failures seldom occur in or near them. However, this type of joint is becoming less and less popular owing to *excessive weight* and instability of solder at extremely low temperatures.

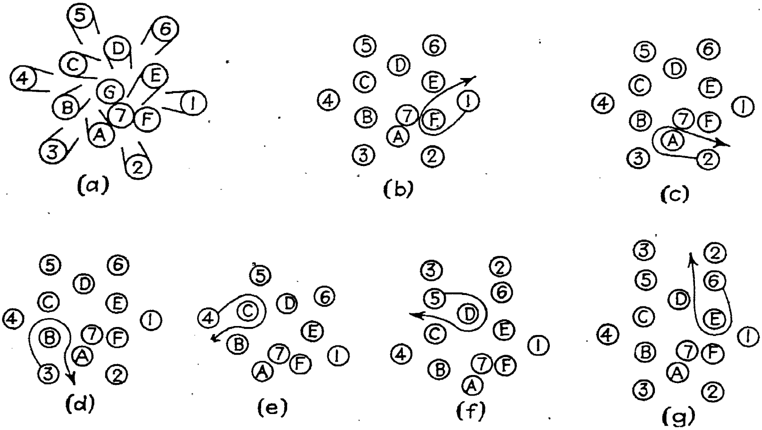

FIG. 206.—Operations in making Roebling splice.

A. Make a navy-type cable splice in the ends of the ⅛-in. 7 by 19 aircraft control cable such that the bearing points of the thimbles will be 14 in. apart. Serve one splice only.

B. Make Roebling splices in the ends of the ⅛-in. 7 by 19 aircraft control cable such that the bearing points of the thimbles will be 14 in. apart. Serve one splice only.

1. The Roebling splice illustrated in Fig. 206 is made as follows:

All operations up to and including the first round of tucks are the same as for the navy-type splice (see Job Unit 50).

Figure 206*a*: shows a cross section of the splice after the first round of tucks has been completed. The views *b*, *c*, *d*, *e*, *f*, and *g* are all taken from this diagram. Note that the core strand No. 7, is pressed close to the core of the standing cable. This set of sketches applies to the second and third rounds, after which the core strand is cut off close. The fourth round of tucks is made by splitting each strand and only tucking one half of it. The fifth round, which is the final round of tucks, is made by splitting the half strands that were used in making round four and tucking the remaining quarter strands. The splice is then completed by pounding it on a wooden anvil with a wooden mallet. All ends are now cut as close as possible to the standing cable. The splice is served by wrapping with No. 7 cord. The serve should be given two coats of orange shellac.

Steps in Making Roebling Splice.—Tucks after first round is complete:

Figure 206*b*: Insert spike under *F*, tuck No. 1 over *F* and back under *F*, coming out between *E* and *F*.

Figure 206*c*: Insert spike under *A*, tuck No. 2 over *A* and back under *A*, coming out between *A* and *F*.

Figure 206*d*: Insert spike under *B*, tuck No. 3 over *B* and back under *B*, coming out between *B* and *A*.

Figure 206*e*: Insert spike under *C*, tuck No. 4 over *C* and back under *C*, coming out between *C* and *B*.

Figure 206*f*: Insert spike under *D*, tuck No. 5 over *D* and back under *D*, coming out between *D* and *C*.

Figure 206*g*: Insert spike under *E*, tuck No. 6 over *E* and back under *E*, coming out between *E* and *D*.

C. Make soldered-type cable terminals in the ends of the ⅛-in. 7 by 19 aircraft control cable, such that the bearing points of the thimbles will be 14 in. apart. (For notes on the soldered type cable terminal see Job Unit 49.)

D. Make hard-wire terminals in the ends of a piece of No. 12 hard aircraft wire such that the bearing points of the terminals will be 14 in. apart. (For notes on loop terminals in high-carbon tinned aircraft wire see Job Unit 48.)

E. Test specimens as made in tension-testing machine to determine ultimate strength.

F. Write report covering tests. Compare the ultimate strengths obtained by the tests for each of the specimens with the ultimate strengths of the wires, as given in Tables XXIII and XXVI in this chapter, to determine the efficiency of each of the various types of terminal. Compare terminal efficiencies obtained with those allowed by the Bureau of Air Commerce of the Department of Commerce to determine the margins of safety. A terminal efficiency of 85 per cent is allowed by the Department of Commerce for hard wire and is considered to be a satisfactory value for the efficiency of other terminals as well.

The following is a typical example of the required calculations:

Wire: $\frac{1}{8}$-in. 7 by 19 aircraft cable.
Strength: (From Table XXVI) = 2000 lb.
Strength of test specimen (from test) = 1910 lb.
Terminal efficiency = $^{1910}/_{2000}$ = 0.95 or 95 per cent
Allowable strength = 0.85 by 2000 = 1700 lb.
Margin of safety = $^{1910}/_{1700} - 1$ = .12 or 12 per cent

Review Questions

1. What properties in wood are desirable for airplane use?
2. Name the factors affecting the strength of aircraft woods.
3. Why is moisture content of aircraft woods important?
4. Explain how you would mix a small batch of casein glue.
5. How long will a batch of casein glue remain useful after mixing?
6. Outline the steps in a complete doping job.
7. What is the purpose of using thimbles with aircraft cables?
8. Describe an aircraft shackle.
9. Where does a spliced-cable terminal usually fail?
10. Describe how a terminal loop in a solid aircraft wire is made.

References

1. Younger, J. E., "Airplane Construction and Repair," Chaps. VI, VII, VIII, and XIV, McGraw-Hill Book Company, Inc., New York, 1931.

2. Koehler, A., "Properties and Uses of Wood," McGraw-Hill Book Company, Inc., New York.

3. Truox, T. R., The Gluing of Wood, U. S. Department of Agriculture, *Department Bulletin* 1500, June, 1929.

4. Truox, T. R., Gluing Wood in Aircraft Manufacture, U. S. Department of Agriculture, *Technical Bulletin* 205, October, 1930. (For sale by Superintendent of Documents, Washington, D. C.)

5. Part 18, Civil Air Regulations, Alteration and Repair of Aircraft: Civil Aeronautics Administration, U. S. Department of Commerce, Washington, D. C.

6. Manufacturers bulletins on doping and finishing aircraft surfaces; Titanine, Inc., Parlin, N. J.; Berry Brothers, Inc., 211 Leib St., Detroit, Mich., etc.

7. Manufacturers bulletins on wires and tie rods; John A. Roebling's Sons Company, Trenton, N. J.; Macwhyte Co., Kenosha, Wis., etc.

8. U. S. Army and Navy *specifications* for wire and cable.

Questions for Thought and Study of References

1. What is plywood? How is it made?
2. Name some woods used in making aircraft plywood.
3. Describe the U. S. Government standard tests for glue. (See Ref. 4.)

4. What are the purposes of doping?

5. What is a thinner? A retarder?

6. How may blushing be prevented?

7. Describe the standard tests for solid aircraft wires and of aircraft cables.

8. Name the parts of a turnbuckle and state the material generally used for each part.

9. How can you determine whether aircraft cable is frayed, that is, if any of the strands are broken?

10. Why should a kinked or bruised solid wire not be used?

CHAPTER XIV

MAINTENANCE CLEANING[1]

Maintenance cleaning is among the first duties of an airplane mechanic. Cleaning at aviation overhaul points is important (1) for safety, (2) for minimum maintenance costs, and (3) for appearance.

Safety, both to passengers and equipment, is naturally of primary importance in aviation. *Only parts which are thoroughly clean can be readily inspected for cracks, flaws, or defects.* Also, when replacing or repairing protective coatings which have been damaged, new coatings should be applied only to clean surfaces to insure durability.

It is easier and quicker for the mechanic to *inspect* and *gauge* parts which have been thoroughly cleaned, so as to see whether the part must be rejected or may safely be put back into assembly. In the overhaul of engines, they can be disassembled in an easier and more orderly manner if they have been given a preliminary cleaning outside, as for instance by a steam-cleaning method. Thorough cleaning also has a bearing on the *maintenance costs* because clean machinery or equipment always lasts longer than that which is neglected.

The third point, *clean appearance,* is of more than casual importance, especially for air lines. Clean equipment adds confidence to the passengers, as it gives an indication of well-serviced equipment.

From this, the airplane mechanic can recognize the importance of doing the cleaning in a proper and thorough manner.

224. Types of Work.—Cleaning may be divided into the following types of work:

1. Engines, primary cleaning for disassembly.
2. Engines, cleaning of parts for inspection and overhaul.
3. Other mechanical parts and fuselage fittings.

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[1] Paragraphs 224 to 229 prepared by H. Liggett Gray, Member A.S.M.E., Oakite Products, Inc., New York.

4. Steel-tube fuselages; cleaning or stripping paint.
5. Cleaning doped surfaces.
6. Cleaning Alclad surfaces.
7. Cleaning interior surfaces, upholstery, etc.
8. Cleaning hangars, shops, floors, etc.

The fundamentals of these varied cleaning operations are sufficiently different so that there are distinctly different methods and types of cleaning materials best suited to each of these types of work.

225. Cleaning Equipment for Mechanical Parts.—It is generally found most efficient to consolidate all the cleaning work into one point where adequate facilities are provided for doing the cleaning safely, speedily, and economically.

The consolidation of the cleaning at one point also enables the man or men doing that work to keep the cleaning solutions and equipment in first-class operating condition constantly, and to learn the "fine points" of the cleaning operation so that the cleaning department can be counted on to supply the inspectors and mechanics with a steady flow of thoroughly cleaned parts to be put right back into assembly. The following is an outline of equipment for a cleaning shop:

Referring to Fig. 207, this drawing gives a typical layout for cleaning all mechanical parts, including engine parts.

1. With a large volume of work, parts should be separated into two classifications for cleaning; the delicate metals of *aluminum* and *magnesium* and their alloys to be handled in tank 1, and parts of steel, iron, and bronze to be handled in tank 3.

2. Tank 2, a cold running rinse, is placed conveniently between the two cleaning tanks. The *cold running rinse* is particularly recommended for the aluminum, as that rinse is used after the soak in the cleaning solution. By thorough rinsing, you avoid any deposits or cleaning solution remaining on the parts and prevent the white deposits which sometimes occur when rinsing is omitted.

3. Tank 4 is generally used more in *production* than in *overhaul*. In production or repair work where many steel or iron parts are going to be put in stock bins and are allowed to lie around for a considerable time (rather than put right back into assembly), they are given a dip in a hot solution of rust preventative, such as Oakite Anti-Rust.

4. Best construction of the tanks is steel plate with welded joints. *Do not use galvanized sheets, as electrolytic action removes the galvanizing*, causing it to be deposited on the parts being cleaned. This same principle applies to dipping baskets or work racks; these should be *plain steel* and not galvanized, so that there is no coating to come off and to deposit on the parts.

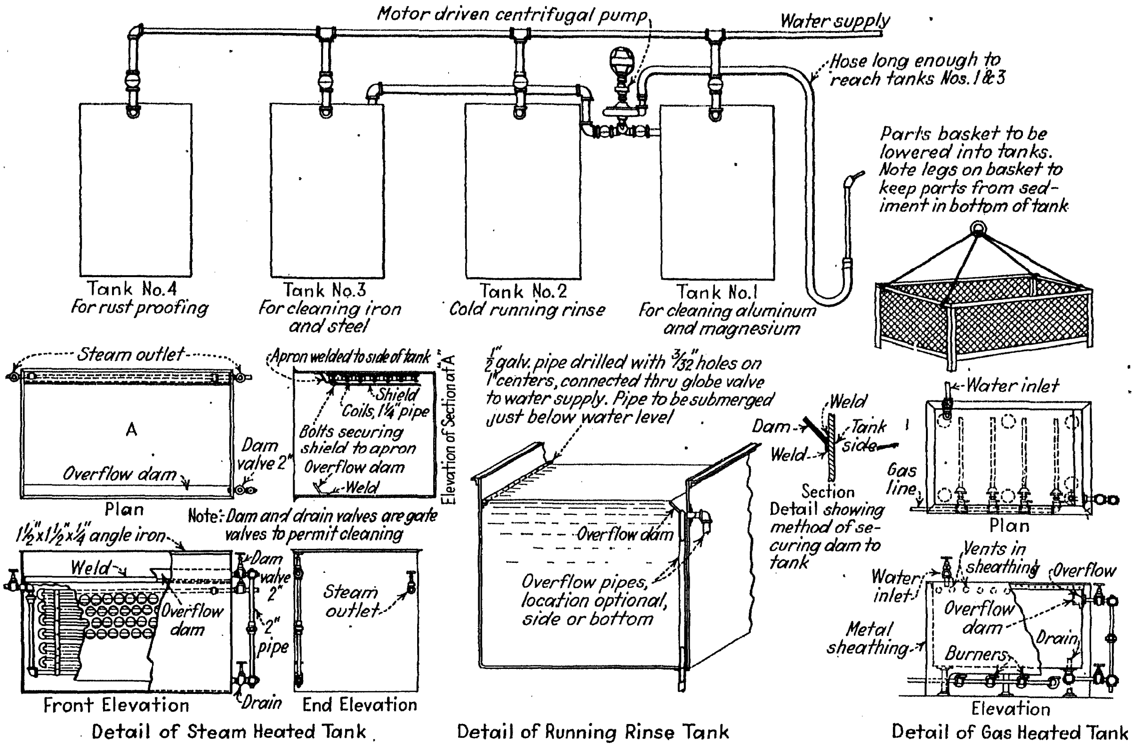
Motor driven centrifugal pump
Water supply
Hose long enough to reach tanks Nos. 1 & 3
Parts basket to be lowered into tanks. Note legs on basket to keep parts from sediment in bottom of tank
Tank No. 4
For rust proofing
Tank No. 3
For cleaning iron and steel
Tank No. 2
Cold running rinse
Tank No. 1
For cleaning aluminum and magnesium
Steam outlet
A
Dam valve 2"
Overflow dam
Plan
Apron welded to side of tank
Shield
Coils, 1¼" pipe
Bolts securing shield to apron
Overflow dam
Weld
Elevation of Section at A
Note: Dam and drain valves are gate valves to permit cleaning
1½"x1½"x¼" angle iron
Weld
Overflow dam
Dam valve 2"
2" pipe
Drain
Steam outlet
Front Elevation
End Elevation
Detail of Steam Heated Tank
½" galv. pipe drilled with 3/32" holes on 1" centers, connected thru globe valve to water supply. Pipe to be submerged just below water level
Overflow dam
Overflow pipes, location optional, side or bottom
Detail of Running Rinse Tank
Weld
Dam
Tank side
Weld
Section
Detail showing method of securing dam to tank
Water inlet
Gas line
Plan
Water inlet
Vents in sheathing
Overflow
Overflow dam
Drain
Metal sheathing
Burners
Elevation
Detail of Gas Heated Tank

FIG. 207.—Cleaning equipment for large repair stations. (*Courtesy of Oakite Products, Inc.*)

5. A *drain* is provided at a low point of each tank, with an outlet valve and connections for the occasional draining and cleaning out of the tanks. It is also most convenient to run a water-supply pipe back of the tanks with a short filling connection to each tank to make up for the water which boils off, or to refill when solutions have been changed.

6. The drawing shows a small pump for circulating the cleaning solutions to a nozzle in order to give some force to the cleaning fluid and thus speed up the work. This is not a necessity, and a large number of shops attain all the speed of cleaning they require by merely soaking the parts in the tanks.

7. The method of heating the cleaning solutions should be the most economical available in the shop.

If it is steam, available all the year around, the most satisfactory, easy, and economical tank heating is by the use of steam coils in the solution. One detail (Fig. 207) shows the correct way of installing a steam coil. The coil should be along the side of the tank, (not the bottom), with plenty of area. An open steam pipe should not be put into the solution, as it will greatly dilute the cleaning solution.

If *steam* is not available, oil-burning or gas heaters are most generally used. For oil burning, the tanks can rest on a brick chamber, arranged so that the heat projects on the bottom and around on the sides of the tank. This gives very economical heating. If gas burners are used, it is always economical to provide a heat jacket to carry the heat of the gas flames up around the sides of the tank. This heat jacket is easily made from light-gauge metal lined with asbestos sheets.

226. Care in Cleaning Mechanical Parts.—Aluminum, magnesium, and the soft-metal alloys are very susceptible to the action of alkaline materials, in fact, if a strip of aluminum, for example, is put in a solution of caustic soda or washing soda and heated, the surface of the aluminum will be dissolved and there will be an evolution of hydrogen gas from the surface in exactly a similar manner as in the action of sulphuric acid on an iron nail, and the same effect and results will be evident, except that there will be a black film produced on the aluminum, owing to carbonaceous materials present. It is apparent therefore, that *aluminum, magnesium, and their alloys must be treated with great care during cleaning* because those metals are readily etched or attacked when soaked in solutions not intended for safe cleaning of delicate metals. This is particularly important, as the machined surfaces of delicate metals require more protection than the cast sections of the same metals.

The cleaning of soft metals is very readily handled, however, by having a separate tank for that work, with a suitable special material such as Oakite Aviation Cleaner; but avoid electrolytic action by keeping those parts from contact with different metals in the solution.

The advantage of the separate cleaning tank 3 (Fig. 207) for steel and iron parts is that one may use a more heavy-duty cleaning solution and speed up the cleaning of steel and iron parts without danger of attack.

Precautions against *electrolytic action* on soft metal parts should be most thoroughly studied. It is always recommended that those parts be so handled that they touch no other metals (such as steel) while in the solution. Consequently, if the parts are handled in metal baskets, the baskets should be lined with wood slats so that the parts do not touch metal. Crankcases can be suspended in the solution by using a rope (and not a chain or cable) or some nonconducting suspension.

227. Cleaners and Care in Their Use.—The following materials find usage around an airplane as solvents and cleaners:

Soap and water, turpentine, alcohol, ether, carbon disulphide, naptha, dope thinner, carbon tetrachloride, chloroform, and combinations of these and other materials sold under trade names.

In the early days of aviation, *fire hazard* was not looked upon as such a serious factor as it is now recognized, and much of the cleaning was originally done with gasoline, benzol, carbon tetrachloride, or mixtures of these materials. These were expensive and hazardous, because of the fire hazard and the possibility of injury to the personnel, but the requirements for cleaning materials had not been so marked as to cause the development of specialized materials previous to 1921 or 1922.

At the present stage of development, cleaning has been given special consideration from a scientific viewpoint, and compounds are on the market for any and all cleaning jobs (see references at the end of this chapter), for example:

1. Stripping paint from metal.
2. Cleaning before electroplating.
3. Removing scale, rust, and other accumulations from materials without injury to the metal.
4. Rust-proofing parts previous to storing in the stock room.
5. Removing oil, grease, and carbon from aluminum and light-weight alloys before inspection and overhaul by immersion in a heated tank of solution.
6. Steam-cleaning chassis before repainting.

7. Removal of paint from tanks and cowling by either immersing in heated tanks or applying with steam.
8. Cleaning after machining and grinding to remove chips and abrasive materials.
9. Washing outside of planes in regular service.
10. Removing oil and grease from exterior of motors.
11. Cleaning interiors of planes.
12. Cleaning benches, desks, and varnished equipment in waiting rooms and offices.
13. Cleaning walls and interior of buildings.
14. Cleaning hangar, shop, and waiting-room floors by mopping.
15. Cleaning toilet facilities in waiting rooms.
16. Reclaiming waste and wiping rags in hangar and shops.
17. Deodorizing planes.
18. Deodorizing and sterilizing toilet facilities in terminals.
19. Sterilizing drinking-water containers.
20. Preventing athlete's foot and other infections in hangar showers.
21. Removing exhaust residues from cowling.

The first rule to follow in using cleaners and solvents is: *Be sure that the cleaner does not remove the finish as well as the dirt,* in other words, be sure you use the proper cleaner for the job. If in doubt, try a small amount on a hidden portion of the surface to be cleaned and note its effect on the finish.

228. Cleaning Doped Surfaces.—The following points should be observed in cleaning doped surfaces:

1. Use care that the finish is not scratched or damaged.
2. Use soap or preparation that contains no alkali or abrasive substance.
3. None of the water should be allowed to reach the internal structure.
4. If the surface is sprayed with a mixture of air and gasoline, fire-fighting equipment should be at hand for immediate use.
5. Wheels of the airplane sling mud on the underside of the wings. This should be removed by allowing the mud cake to soak thoroughly in an application of water. No attempt should be made to scrape the mud off in a dry state, or the finish will be damaged. Hard rubbing with rag may cause the grit to scratch the finish.

229. Cleaning Alclad Surfaces.—(The following procedure is given in the Handbook of Instruction for the Maintenance of the Model DC-3 Douglas Airplane.) *Note that the general method to be followed is the important point for the student to learn.*

1. The following procedure is recommended for cleaning exterior surfaces of this airplane. This applies to the fabric as well as to the metal covered surfaces:

2. A solution of Turco, Composition Number 400 or equivalent [Par. 233] should be used, made up in the proportion of 3 pounds to 50 U.S. gallons of water. The normal solution to use for hand work is one ounce to each gallon (1 oz. to 1 gal.) of water. Apply this solution with a soft-bristle brush by starting at the bottom and working up. Care must be exercised in cleaning the top of the fuselage that the solution does not run down the sides, as it will leave a streak that is practically impossible to remove. After the surface has been washed with the solution, it should be rinsed with clear water, using a soft-bristle brush for the first rinsing and a long-handled mop for the second. Surplus water should be wiped off with a dry rag. The fairings for the wing attachments should be removed every 300 flying hours and the surface below cleaned of stain caused by the solution.

3. This solution in the amount recommended is free from any properties that would cause corrosion or excessive stain; however, if the application is not properly handled, a light film or streakiness is liable to result, but this neither attacks nor injures aluminum or other surfaces.

4. This composition, in solution, develops suds or foam. Its reaction is very much like that of a soapy solution, and only a sufficiently large area, which can be rinsed before the solution dries, should be covered at one time. If the work is being done on the outside, it is recommended that running water be available and that small areas should be covered, and then rinsed before the solution dries.

230. Interior Cleaning.—The rules to be followed are as follows:

1. Clean coveralls should be used by mechanics doing interior work or cleaning, so as not to carry grease and dirt to the upholstering.
2. To clean the fabric upholstering, use the vacuum cleaner, stiff brush, or whisk broom to remove the dust, while the upholstering is beaten lightly with the hand, stick, or a carpet beater.
3. In a manner similar to (2), clean the interior of the doors, the sides, and the ceiling of the cabin.
4. Cloths rung out of boiling water rubbed lightly over mohair or velour will restore much of their original beauty.
5. To remove grease and other stains, apply carbon tetrachloride or a good commercial cleaning fluid with a soft cloth and rub briskly (gasoline and benzine only spread the spots). After the cleaning fluid has evaporated, apply a moistened cloth, and press with the flat iron on top of the moistened cloth.
6. To clean imitation leather and other coated upholstering, first clean the folds and seams thoroughly with a vacuum cleaner, then wipe with a cloth dampened in weak ammonia water, and dry with a woolen or flannel cloth.

231. Cleaning Shop and Hangar Floors.—'Sloppy" working quarters in general indicate "sloppy" work. Shop and hangar floors should be kept clean, not only from the standpoint of appearance but also from the standpoint of safety from accidents and fire. Proceed as follows:

1. A good cleaner such as, for example, Turco Composition No. 57 or Okemco (see References at end of chapter for address) should be used. Cleaners should be diluted according to manufacturers instructions.
2. The cleaner used should be noninflammable as are those of (1).
3. A good stiff deck brush with a rubber squeegee will be very helpful for heavy-duty work. A mopping tank on castors will save time over the use of buckets, since it will make it possible to prepare a considerable quantity of solution all at one time. The floor should finally be rinsed down with a garden hose if drainage conditions are satisfactory; otherwise excess water should be picked up with a dry mop.
4. Grease spots caused by parked planes and the greasy area around the lubrication department may require special solutions which any reliable cleaning products' company will recommend.

232. Cleaning and Polishing Glass.—Proceed as follows:

1. Prepare a small container of equal parts of alcohol and water.
2. With a sponge moistened in this solution rub the glass until clean.
3. Now polish the glass with a soft dry lintless cloth or tissue paper.
4. An alternate method is to use a solution of water and household ammonia, about 1 tablespoon of ammonia to 1 quart of water.
5. Clean the glass with this and polish with chamois skin wrung out of the same solution.
6. Care should be taken that the cleaning fluid does not touch the finish around the window as the effect will be very bad.

233. Cleaning Practices Recommended by Manufactures. *Aluminum Alloys.*[1]—The following cleaners, among others, have been examined by us and have been found to have no harmful effects upon aluminum. A number of cleaners of the general type of those indicated have been in use by various manufacturing and servicing activities in the field and have apparently given satisfactory results:

1. Oakite Aviation Cleaner, manufactured by Oakite Products Company of New York. When speaking of this cleaner, the complete title, as stated, should be given to avoid accidentally getting other cleaners manufactured by this company that are not entirely suitable for this purpose.
2. Diversey Triple A, or Diversey 3S Aluminum Cleaner, manufactured by Diversey Corporation of Chicago.

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[1] "Report on Recommended Practices for Construction and Repair of Aluminum Alloy Aircraft Structures," by Aluminum Company of America.

3. Wyandotte Aluminum Cleaner 4X, manufactured by J. B. Ford Company of Wyandotte, Michigan.
4. Turco Compo. No. 400 Aero. Cleaner, manufactured by Turco Products Inc., Los Angeles, California.

Light coatings of wax, oil, or grease will do much to prevent the formation of disfiguring deposits on parts made from Alclad materials subjected to salt-water conditions. Portions of floats and hulls below the water line will have to be cleaned free of barnacles and marine growth periodically as necessary. Land planes may not require extensive cleaning to maintain a satisfactory appearance.

Fuselage Cleaning (Maintenance and Service Manual, Boeing 247).—All joints and seams are sealed by means of Goodrich "Plasticon" applied when the body sections are riveted or screwed together. Fuselages are given a water spray or rain test when removed from the final assembly jig. This is to inspect for water leaks prior to installation of the cabin lining. Plasticon is a rubber compound, soluble in gasoline, kerosine, carbon tetrachloride, and similar fluids usually employed for cleaning. For this reason these liquids should not be used for cleaning the fuselages as they will eventually dissolve the Plasticon applied between the seams and joints. It is, however, resistant to water.

234. Cleaning Fuel and Oil Tanks for Welding (Maintenance Instructions, Shrike Design 60A, the Curtiss Aeroplane and Motor Co.).—In order to prevent damage to tanks during rewelding, and possible injury to personnel, it is suggested that the following procedure be used for the removal of gasoline and gasoline vapor from fuel tanks prior to effecting repairs:

a. Remove fittings, open vents, caps, etc.

b. Run a good steam of boiling hot water through the tank for one hour. Water should enter at bottom and overflow at top.

c. Blow compressed air (low pressure) through the tank for 1 hr., with all vents open.

d. It is important to make repairs immediately after the above procedure is carried out. Do not permit tank to stand around prior to welding.

The following alternate procedure may be used:

Steam out the tank with live steam for about 3 hr., after which the tank should be filled about one third full with fresh water, shaken for 2 or 3 min., and then emptied. The tank should then be blown through with compressed air for about ½ hr. until the odor of gasoline has completely disappeared. Open top and bottom vents during the application of heat.

Review Questions

1. Name seven common dirt solvents and cleaners.

2. If gasoline is used for cleaning, what precautions must be taken?

3. Should rags used in washing mud from airplanes be used elsewhere? Why?

4. What precautions should be used in spraying water over an airplane?

5. Outline a method of cleaning a doped surface.

6. How would you clean an Alclad surface?

7. What would you use for removing grease spots from a seat cushion?

8. How would you clean a hangar floor? Name materials to be used and describe method.

9. Why should not duralumin be suspended in a cleaning solution by means of a chain?

10. Why should wooden trays be used in dipping airplane parts in cleaning solutions?

References

1. "Oakite Cleaning Materials in the Aviation Industry," Oakite Products, Inc., New York.

2. "Special Service Report," Turco Products, Inc., Los Angeles, Calif.

3. Nobles, L. E., and J. A. Roenigk, "Cleaning and Lubricating," McGraw-Hill Book Company, Inc., New York.

4. Descriptive material furnished by soap and cleaning-compound manufacturing companies.

5. Any recently published elementary text on practical chemistry.

6. "Encyclopaedia Britannica" under the heading of Soap.

Questions for Thought and Study of References

1. What are the causes of hard water?

2. How would you relieve the hardness of water?

3. What is soap?

4. What causes metals to become dull or to tarnish?

5. Give a satisfactory method of polishing metal.

6. How would you clean a landing-light reflector?

7. How would you put out a gasoline fire?

8. What is meant by electrolytic action?

9. How is static electricity developed?

10. What precaution is used in preventing fires around airplanes from static electricity discharges?

CHAPTER XV

MAINTENANCE OF PROPELLERS

The airplane mechanic is often assigned the duty of daily maintenance of propellers as a part of his regular routine. The repair of propellers requires the service of specially trained mechanics and the use of special tools. Propeller repair is out of the scope of duties of the airplane mechanic, hence out of the scope of this book.

It is assumed that the mechanic will become familiar with the mechanism of propellers through the use of literature published by manufacturers (see References), hence no unnecessary descriptive matter is included.

Safety Precaution.—An airplane propeller on an airplane should never be touched:

1. At a time when the engine is warm.
2. Unless engine ignition switch is first inspected and noted in the off position.

235. Propeller Nomenclature.—Figure 208 shows a typical two-bladed propeller with the names of the parts. A propeller develops thrust by its reaction on a mass of air, which it pushes backward. This moving mass of air is called the *slipstream.* The effect of the slipstream at the rear of the airplane is called the *propeller wash.* The propeller slipstream begins many feet in front of the propeller. On account of this, *it is dangerous to walk in front of a moving propeller,* as one may be sucked into the blades.

When the propeller is operating with the airplane stationary, the blades cut out an imaginary disk in the air. This is called the *disk of the propeller.* If the propeller disk is extended indefinitely, it becomes the *plane of the propeller.* Particles thrown off from the propeller by the *centrifugal force* will shoot out in this plane. It is therefore a good practice to *avoid the plane of the propeller when the propeller is running.*

Each element of a blade of a propeller resembles a wing section (see Fig. 208*b*). This element has a leading or entering edge, a trailing edge, and camber. The section is called an *airfoil section*, just as a wing is called an airfoil section.

The propeller section develops *thrust* in the same way that a wing develops *lift*. The propeller section, however, travels in a circle at the same time it is climbing (traveling forward). The path is called a *helix*. If the path of a propeller-blade element in the air could be photographed, it would resemble the threads of a screw. (A propeller is sometimes known as a "screw.")

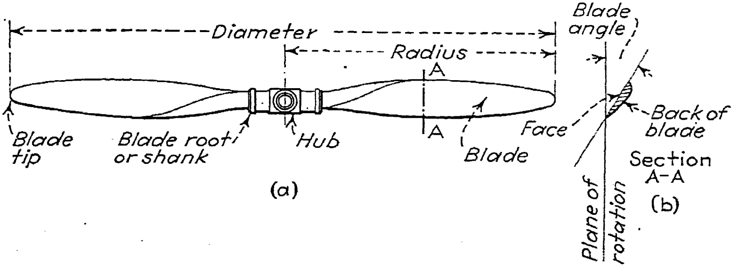

FIG. 208.—Parts of a propeller.

Since all elements of the propeller blade must travel forward the same distance per revolution, the elements nearest the hub must travel along a steeper helix than the elements at the tip. The *blade angle* is made greater near the hub to provide for this.

236. Stresses on a Propeller.—A propeller is the most "overworked" part of the airplane. The stresses developed are:

1. *Bending* in plane of rotation by the torque of the engine.
2. *Centrifugal Force.*—A portion of a blade, of about 1 lb. weight, near the tip of a 10-ft. propeller operating at the usual rated speed, develops in the order of 2 to 5 tons centrifugal load. The unbalanced force caused by the loss of one blade is sufficient to tear a motor out of the airplane.

A piece of propeller slung off from the tip will have a velocity very little less than a rifle bullet.

3. *Bending Due to the Thrust Load.*—This is partially counterbalanced by the centrifugal force.
4. *Vibration.*—This is the worst condition. The worst form of vibration is *flutter*. A propeller which has a tendency to flutter will not last long. *Resonant vibration* means a certain failure in a short while.

Resonant vibration means that the impulses tending to vibrate the propeller (such as engine impulses due to the fuel explosions) have the same frequency of occurrence as the natural frequency of vibration of the propeller. As an example of resonant vibration perform the following simple experiment:

a. Tie a small bolt to one end of a thin rubber band about 10 in. long.

b. With the other end of the band in the fingers, suspend the bolt, and note its natural *frequency* of vibration up-and-down.

c. Now move the hand with the rubber band up and down at the same frequency and note how the bolt gains in amplitude (displacement from the position of rest).

Vibration causes fatigue failures. We have noted previously that small scratches, abrasions, etc., in the metal very quickly start a fatigue failure, since the stress is unduly concentrated at such points. This explains the necessity that these small defects must have daily attention.

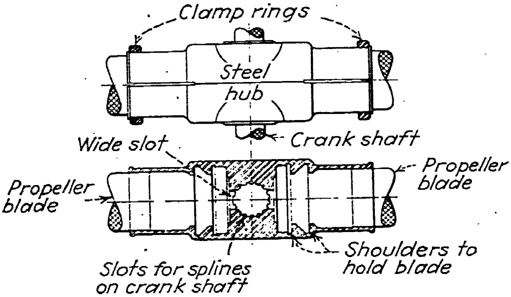

FIG. 209.—Hub of adjustable-pitch propeller.

237. Types of Propellers.—The types are:

1. Wooden, blade angle fixed; used on small airplanes only.
2. Metal, fixed blade angle; little used.
3. Adjustable pitch (detachable blades); metal, aluminum alloy, and steel. Blade angle is set in the shop (see Fig. 209).
4. Controllable pitch. The pitch may be controlled in flight; generally refers to propellers which have two blade-angle settings, one for take-off and one for cruising flight. The blades are controlled by mechanical means or by oil pressure.
5. Variable pitch. Any blade angle may be set in flight.
6. Constant speed. The blade angle is set, in flight, automatically to hold the engine to a constant speed. It is controlled by a governer.
7. Feathering multiengined types. The blade can be "feathered" in flight so as to offer the minimum resistance to flight and to stop engine rotation.

238. Care of Aluminum-alloy Propellers.—The following instructions, which will apply to any aluminum-alloy propeller, are reproduced by permission from "Maintenance of Metal Propellers," by Hamilton Standard Propeller Company:

Installation.—Proper installation of metal propellers is highly important if satisfactory operating conditions are to be obtained:

1. Hub cones and seats should be carefully inspected to insure firm contact. If *galled*, the marks or high spots should be removed by use of fine emery cloth, or the cone should be replaced.
2. Front cones should be inspected to insure that the halves are *matched* by number.
3. Light oil should be applied to the cone seats and shafts before installation of the propeller.
4. The force exerted by one man using a bar two or three feet in length is considered ample to properly tighen hub retaining nuts, if the cones are seating properly.
5. After test flight hub retaining nut should be checked for tightness.
6. After installation, the propeller should be rotated through an arc of 180° for the purpose of checking the track. If the error exceeds 1/8 inch, the propeller should be checked and corrected by an authorized service station. [See Job Units 53 and 54.]

239. Daily Inspection and Maintenance.—Hubs and blades under abnormal operating conditions may be subjected to severe strain tending to induce fatigue.

1. Hubs and blades should be inspected daily as mounted on the plane.
2. Hubs should be carefully inspected for fatigue cracks which usually start at a point near the blade shoulders on the parting line.
3. When propellers are subjected to operation on cinder runways or in water spray, the leading edges of the blades may become pitted and ragged. This in time seriously affects the efficiency of the propeller by destroying the true airfoil section. If erosion is eliminated in the early stages by means of crocus or fine emery cloth, the blades will retain their efficiency for a longer period of time and the slight effect on balance will not be noticeable in operation.
4. It has been found advisable for seaplane installations, where propellers are subjected to corrosion from salt water, to smooth the blades with crocus cloth and apply a coating of oil after each day's flying.
5. Nicks and sharp dents on the leading edges, or gashes on the blade faces are particularly dangerous, as they greatly reduce the fatigue strength at that particular point. A failure may result unless they are removed promptly. (All marrs on the surface of the blades are "stress raisers" and cause a stress concentration which may raise the stress beyond the endurance limit, resulting in a fatigue type failure.)
6. Sharp dents and nicks and gashes may be removed locally without the necessity for reworking the entire blade surface. (See Fig. 211.) A

curved "riffle" file is recommended for use in removing the sharp base of the nick. Fine emery cloth or crocus should be used for polishing. Care should be taken in removing nicks from the blade face to insure that the thickness is not reduced more than is necessary.

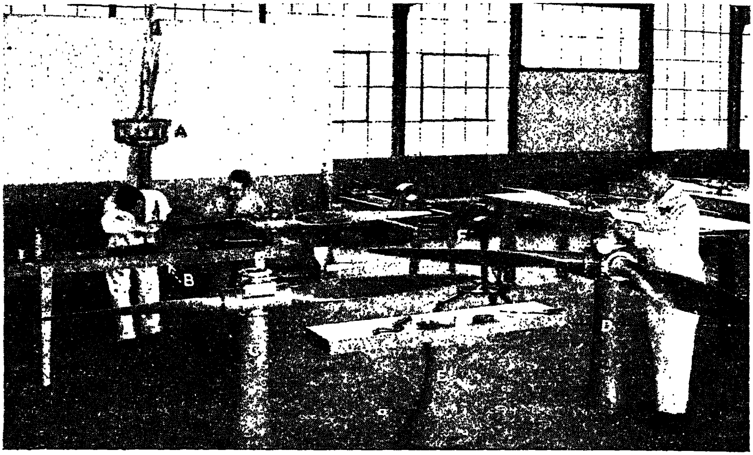

FIG. 210.—Propeller-department equipment. (*A*) Balancing stand, (*B*) table for checking and setting pitch angle of adjustable-pitch propeller, (*C*) and (*D*) pedestals to accommodate two-blade and three-blade controllable-pitch propellers, (*E*) repair stand, and (*F*) buffer. (*Courtesy of Parks Air College.*)

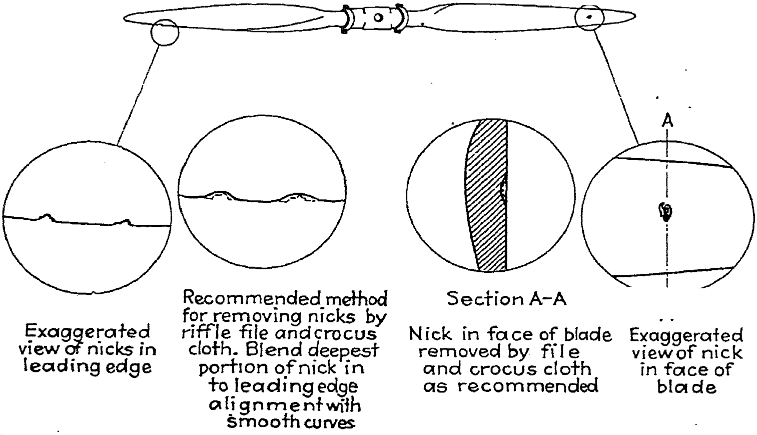
A
Section A–A
Exaggerated view of nicks in leading edge
Recommended method for removing nicks by riffle file and crocus cloth. Blend deepest portion of nick in to leading edge alignment with smooth curves
Nick in face of blade removed by file and crocus cloth as recommended
Exaggerated view of nick in face of blade

FIG. 211.—Typical nicks in aluminum-alloy propeller blade and method of removal. (*Courtesy of Hamilton Standard Propeller Company.*)

It is recommended as an added safety precaution that the surface, after removal of a nick, be etched, examined with a magnifying glass (to insure that the nick is entirely removed and that a crack has not started), and then polished locally. Propellers having very severe nicks or gashes should be sent to an authorized service station or to the factory for repair.

240. Assembly and Balance.—Proceed as follows:

1. Propellers should be assembled on a suitable spline adapted to insure correct alignment of the splines in the hub halves.
2. Two-piece clamp rings should be placed on the hub with the bolt side centered on the hub centerline away from the engine, except where the engine or cowling does not provide sufficient clearance for the hinge pin. In this case, the bolt sides of the clamp rings should be placed at 45 deg. to the shaft-bore centerline (on opposite sides) and 90 deg. apart.
3. One-piece clamp rings should be placed on the hub with the bolt on the exact centerline of the hub, away from the engine.
4. To check the balance, the hub should be fitted with a suitable adapter and arbor and placed on a balancing stand and balance observed with the blades in a horizontal position.
5. The blades should be set at the proper angle and pulled out firmly against the shoulders before clamping them into position. Unless this is done, the blades will be pulled out by centrifugal force and the propeller will become unbalanced.
6. With the propeller in vertical position on the balancing stand, the lower clamp for each blade should be loosened and the blade pulled to rest against the hub shoulders. The clamps should then be tightened and horizontal balance again checked.
7. To correct horizontal balance, lead may be added or removed from the concentric hole in the blade end.
8. The balance should then be observed with blades in a vertical position; if correction is necessary, the clamping rings, when bolts are located on hub centerline, may be moved equally off center in the same direction toward the light side of the blades. Movements of ¼ in. should be sufficient to obtain vertical balance.
9. When clamp-ring bolts are in the 45-deg. position, owing to engine or cowling interference, correct vertical balance may be obtained by moving one ring only toward the front centerline for a distance which should not exceed ½ in. for best results.
10. An arrow should be stamped on the hub shell and on the clamp ring to indicate correct location.
11. Under no circumstances should clamps be moved toward the hub center to effect horizontal balance.
12. Blade angles at the 42-in. radius (or 30-in. radius) should be alike within 0.1 deg.
13. The "track" of the propeller may be checked by mounting the propeller on a suitable mandrel and swinging the blades through an arc of 180 deg.

An error in track exceeding ⅛ in. should be corrected. Excessive error in track will result in dynamic unbalance (see Job Units 53 and 54).

241. Periodic Inspection and Overhaul.—At intervals of approximately 200 hr. of flying time propellers should be sent to an authorized service station for thorough inspection of the hub and etching inspection and refinishing of the blades. Propellers operated under abnormal conditions resulting in damage to blades, owing to pick-up from cinder runways, etc., will require more frequent servicing.

1. For thorough inspection, the hub should be disassembled, thoroughly cleaned, and the De Forest Magna-Flux method used to detect fatigue cracks. If the De Forest method is not available, the hub should be carefully inspected by use of a suitable magnifying glass.
2. Splines and cone seats should be carefully inspected for wear.
3. Hubs on which the splines are worn in excess of 0.002 in. should be replaced, as continued use would probably result in extensive and costly damage to the engine shaft or propeller hub.
4. Front-cone halves should be inspected to insure that they are matched by number.
5. Rear cones may be lapped to secure satisfactory seat. This work, however, should only be attempted by an authorized service station having suitable equipment.
6. The blade surface (exclusive of the shank) should be lightly sanded to remove nicks and etches, using a 10 to 20 per cent aqueous solution of caustic soda, which consists of 1 or 2 lb. of commercial caustic soda for each gallon of water used. When the surface is well blackened, it should be rinsed with pure water, then the caustic action should be neutralized by swabbing with a solution composed of 1 part commercial nitric acid to each 10 parts of water used. For best results, the caustic soda solution should be heated to 160° to 180°F. By this method the blade is immersed for only 15 to 30 sec., which gives a uniform etch of proper depth and leaves a bright surface, permitting ready detection of any cracks. *Any suspected cracks should be given a local etch and again examined.* After etching, blades should be polished with a buffing wheel. All paint should be removed before etching.
7. Small inclusions which form longitudinal lines owing to the forging process, are not important, but any *cracks or seams across the blade are usually a sign of impending fatigue failure and are cause for replacement.*
8. The limits to which blade sections can be reduced incident to removal of nicks and gashes without unduly weakening the blade are specified in Repair Regulations No. 3. For field guidance it should be noted that neither the thickness nor the width of the outer 12-in. tip section should be reduced in excess of 10 per cent of the blade drawing dimensions, except that the outer 6-in. tip section may be modified as becomes necessary, to provide a true-airfoil section.

9. Care should be exercised not to etch the shank portion of the blades except as recommended, as this would affect the fit in the hub. A light local etch about 2 in. in diameter is permitted on the clamping section of the blade shank at the critical points in line with the leading and trailing edges of the airfoil section. (See Points *A* and *B* in Fig. 212.) Care should be taken to remove all traces of this local etch by polishing. Any transverse cracks are cause for rejection.

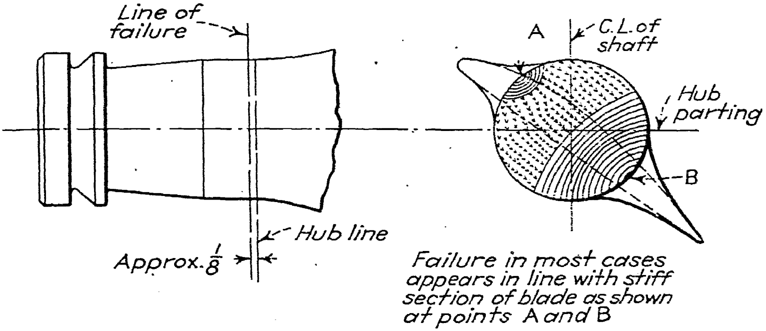
Line of failure
Hub line
Approx. $\frac{1}{8}$
A
C.L. of shaft
Hub parting
B
Failure in most cases appears in line with stiff section of blade as shown at points A and B

FIG. 212.—Typical propeller-blade failure. (*Courtesy of Hamilton Standard Propeller Company.*)

10. In some cases where hubs of early manufacture are still in use, interference has been noted between the radii at the top of the hub shoulders and the fillets at the base of the corresponding blade shoulder (as shown in Fig. 213).

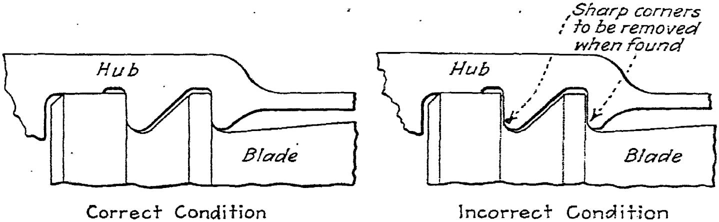

FIG. 213.—Seating propeller hub.

11. Where interference is found, the top of the hub shoulder should be worked down until interference is eliminated. Where machining facilities are not available this work can be done by hand filing the hub shoulder to approximately $\frac{1}{8}$ in. radius. No work should be done on the blade shank, as this may result in weakness which would impair the safety of the assembly.

A. Major Repairs to Propellers.—Hubs which have been involved in an accident should be inspected by a competent service station using the De Forest Magna-Flux method to insure that they are not fractured. *Hubs which have been twisted or sprung in such a manner as to destroy perfect blade alignment cannot be repaired and must be replaced.*

Propeller blades involved in an accident can, in many cases, be satisfactorily repaired. *Too much emphasis cannot be laid on the necessity for having all repair work done by experienced personnel at the factory or authorized repair stations.* Several instances have come to notice where repairs have been attempted by untrained workmen, unacquainted with strength factors which must be maintained and elastic limits which must be respected. In some cases, alloy blades have been straightened by heating with a blow torch, *thus reducing the ultimate strength about* 40 *per cent.* In other cases, cracked hubs have been welded, thus destroying the tensile strength of the chromium-vanadium steel at the point where most needed and creating a condition where a *complete hub failure would be almost certain.*

If the blades are slightly bent or twisted, repairs can be made by authorized service stations. Where the damage is extensive, the blades must be *annealed* before straightening to avoid exceeding the elastic limits of the material.

Full instructions covering this work are given in Repair Specifications No. 3, which are available to authorized service stations and which include a graph indicating the maximum angle of bend which may be repaired with and without annealing. Blades thus damaged must be re-formed in the annealed condition, then re-heat-treated to regain the tensile strength, and completely refinished. Blade repairs involving annealing and re-heat treatment should never be attempted, except by the factory or certain authorized service stations in cooperation with the Aluminum Company of America, where proper facilities for heat treatment are available.

Blades which are bent in edge alignment must be annealed in a suitably controlled furnace and straightened while hot. This work shall be done only at the factory where adequate facilities are available. After straightening, the blades are returned to the Aluminum Company for re-heat treatment.

B. Operating Adjustments.—Under normal conditions, propeller-blade angles should be adjusted to provide the rated engine r.p.m. and horsepower in full-throttle level flight. For heavily loaded planes and for some special purposes the blade angles may be reduced to give an additional 5 per cent increase in r.p.m. allowed by Department of Commerce Regulations.

Under certain circumstances it may be desirable to hold the engine below the r.p.m. that is normal for a given throttle opening by *increasing the blade pitch.* Care must be exercised, however, that cylinder pressures are not thereby increased to a point where engine life and reliability are sacrificed to a material degree. The advice of the engine manufacturer should be secured as to the safe limit in each case.

Further in this connection, *it is important that erroneous or misleading conclusions are not reached by overpitching the blade.* Some reports of extraordinary improvement in cruising efficiency with the same propeller at different pitch settings or with different propellers have been found to ignore the fact that cruising speeds must primarily be related to the actual power being taken from the engine rather than to engine r.p.m.

Generally speaking, increased cruising speed at the same r.p.m. is possible with any propeller if the throttle is opened wider and more power taken from the engine, but the r.p.m. held down by increasing the blade-pitch angles—subject to the practical limitation as regards engine life and reliability, as pointed out above.

It is often desirable for the operator to have a rough check on the suitability of a propeller for the plane and engine on which it is being used. *In general practice the angle of attack of the propeller at full-throttle level flight should be between* 1 *and* 3 *deg. when obtaining the rated r.p.m.* This may be checked in the following manner:

Hubs are provided with a scale marked in degrees. This scale indicates the pitch angle at a point 42 in. from the crankshaft axis for propellers greater than 7 ft. 5 in. in diameter and at the 30-in. radius for propellers of this or smaller diameter. To find the angle of attack, divide the maximum speed of the plane in miles per hour by the rated engine r.p.m., and multiply by 4. This figure represents the *tangent* of the angle of advance at the 42-in. radius. The corresponding angle of advance may be obtained from a *table of tangents.* To find the angle of attack, subtract the angle of advance from the blade setting, as indicated by the hub marking after the blade angles have been adjusted to give rated engine r.p.m. in full-throttle level flight. Should the propeller be less than 7 ft. 6 in. in diameter, it is necessary to find the tangent of the angle at the 30-in. radius. This may be done by multiplying the tangent as found for the 42-in. radius by $\frac{7}{5}$. The corresponding angle of advance is then obtained and compared with the indicated blade setting. The angle of attack is the difference as before. If the angle of attack is greater than 3 deg., it is usually an indication that the propeller diameter is too large. There are, of course, exceptions to this rule, which is intended to give only a rough but practical estimate as to whether a replacement propeller is operating efficiently. *The plane manufacturer's recommendations should be followed wherever possible.*

G. Vibration.—The question of vibration in the power plant, propeller, and mounting is deserving of serious consideration. One, but only one, of the obvious causes is the propeller.

The propeller may cause vibration by being either out of dynamic or aerodynamic balance. Hamilton Standard propellers are so designed and constructed that the centers of gravity of all the sections lie in a straight line, so that if they are in static balance, they are also in dynamic balance. Static balance may be readily checked on a balancing stand, which is a part of the equipment of all service stations (see *A*, Fig. 210).

Blade contour is rigidly controlled during manufacture, so that when blade angles are the same at the 42-in. radius, the propeller will be aerodynamically balanced.

Vibration frequently occurs at certain speeds and is negligible at other speeds. This may be the result of the natural period of vibration of some of the parts coinciding with the rate of engine impulses or with the rate of revolution. The engine should be checked to insure uniform power impulses, correctly adjusted valve tappets, and ignition O. K. The engine mount and fittings should be inspected for cracks and tightness.

Favorable results have also been obtained by increasing or decreasing the tension on the resilient pads commonly used in the engine-mount structure or by substituting new pads commonly used in the engine mount structure or by substituting new pads of greater or lesser resiliency.

The natural period of most Hamilton Standard Propellers is well outside the normal operating range.

242. Care of Steel Propellers.—The following instructions are summarized from "Instruction Book" for Lycoming-Smith controllable propeller. They have a general application:

A. Service Maintenance:

1. *Coating with Oil.*—On completion of each day's flying and immediately after each cleaning, all outside surfaces of each propeller should be thoroughly coated with clean engine oil. A propeller not in use should be thoroughly coated with clean engine oil as often as necessary to prevent corrosion.

2. *Cleaning.*—Outside surfaces of the propeller hub and blades may be cleaned with warm water and soap, domestic gasoline or kerosene. Except in the case of a few repair operations, steel wool, steel brushes or any material that will scratch the propeller surfaces should not be used. After cleaning, the surfaces of the propeller should be rinsed with fresh water and dried. A thin coat of clean engine oil should then be applied to all surfaces of the propeller. The cleaning of the inside surfaces of the propeller is an overhaul function and should not be attempted by service personnel.

3. *Removal of Salt.*—After being subjected to salt water, outside surfaces of the propeller should be flushed off with fresh water, in order to remove all traces of salt. All parts should then be thoroughly dried and coated with clean engine oil.

4. *Repair.*—The repair of a crack or bend in a blade or a deep cut which may cause a crack in the propeller *should not be attempted without specific instructions in each case.* Raised edges of cuts, scratches, etc., may be burnished down or dressed off by honing if a crack is not likely to result from such honing. Metal should *never* be removed from blades under any circumstance other than for dressing off raised edges. Small dents in blades need not be removed, inasmuch as the operations involved in removing same are considerably more harmful. Corrosion and raised points of nicks, scores, galls, etc., on the surfaces of the hub should be removed by careful filing and hand stoning.

JOB UNITS

Job Unit 52. Report on Propellers

Outline of Work

a. The several types of propellers on hand are to be described, in detail, as to their structure.

b. They are to be compared, as to their advantages and disadvantages.

c. A propeller is to be checked for blade angles at various stations outward from the hub, and a chart made of the results.

Tools and Materials Required.—Level, protractor, table (see *B*, Fig. 210), tape measure.

Discussion.—Propeller designers have constantly worked for *higher efficiency* and *lower maintenance costs.*

Propellers may be compared by setting up an outline such as the following:

	Type 1	Type 2	Type 3
First cost........			
Maintenance cost.			
Service life........			
Weather resistance			
Etc..............			

This outline is incomplete but will serve as a guide. See Par. 235 for theory of the blade angle.

Procedure.—Study the propellers in the laboratory and write a description of their structural differences. Results of observation may be supplemented by reference to texts such as "Simple Aerodynamics," Monteith and Carter; Dykes' "Engine Instructor"; or "Simplified Aerodynamics," Klemin.

By observation and reference to the texts if necessary, write out a list of advantages and disadvantages for the three types of propellers. The form of outline given in the discussion may be used if desired.

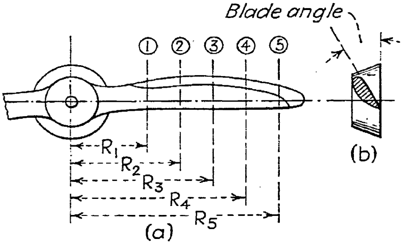

FIG. 214.—Sections of a propeller blade.

Determine the blade angles of a wooden propeller in the laboratory at the following stations (see Fig. 214):

Station 1 — $R_1 = 24$ in.
Station 2 — $R_2 = 30$ in.
Station 3 — $R_3 = 36$ in.
Station 4 — $R_4 = 42$ in.
Station 5 — $R_5 = 48$ in.

Use a level protractor for measuring the angles. Take stations on a good blade which has not been damaged.

Plot a curve of the geometric pitch as in Fig. 215. Write an explanation of the fact that the curve is not a straight horizontal line. Sketch cross-sections of the blade of the sectioned propeller and refer to these sketches in making your explanation.

Hand in the written report.

Job Unit 53. Checking Propeller Track

Outline of Work.—The track of two or three propellers of airplanes on the line are to be checked.

Tools and Materials.—Surface gauge, scale, stand for surface gauge.

Procedure (see Fig. 216)

1. See safety precaution at the beginning of this chapter.
2. Care should be taken that the airplane remains perfectly stationary during the check.

3. Mark corresponding points on the leading edge of each blade about 4 to 10 in. from the tip, equal distances from the center of the hub.

4. Set the scriber of the surface gauge as in Fig. 216, so that it just touches the marked point on blade 1.

5. Rotate the propeller and check distance of scriber point from the marked point on blade 2. A perfect check is desirable, but a $\frac{1}{8}$- to $\frac{3}{16}$-in. deviation is sometimes tolerated.

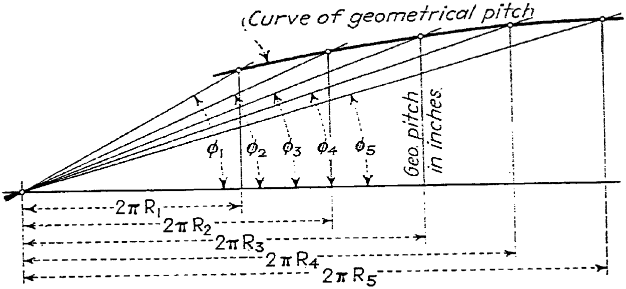

Fig. 215.—Geometrical pitch of a propeller.

Job Unit 54. Checking Track of Metal Propellers

(U. S. Air Corps Method)

Outline of Work.—The tracking of the blades of a two- or three-bladed aluminum-alloy blade is to be checked.

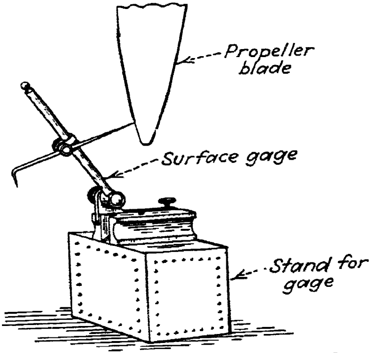

Fig. 216.—Checking the track of an airplane propeller.

Tools and Material.—Aluminum-alloy and steel propeller, propeller-blade protractor, surface gauge, scale. Checking table (see *B*, Fig 210).

Procedure.—Owing to the permissible variations in the radii and other dimensions of detachable blades, the tracking of propellers having such blades cannot be accurately determined by checking from the tips, the leading edges, or the trailing edges. The correct method is as follows:

1. Insert the required assembling and checking bushing into the propeller hub and place the propeller on the spindle of the propeller-checking plate, so that the faces or flat sides of the blades are up.

2. Carefully check the angle setting to see that each blade is set at the correct angle. Tracking cannot be accurately checked unless each blade is set at exactly the same angle.

3. Starting with the station at which the blade angle is set, and at each 6-in. point from that station to the blade tip, draw a straight lead-pencil line across the face of each blade, 90 deg. to longitudinal centerline of blade. On each of these lines, with the aid of a steel or other suitable square, mark off a point 1 in. in from the trailing edge. These markings must be accurately made on each blade.

4. Turn the propeller so that the centerline of the first blade to be checked is approximately parallel to the centerline of the checking plate.

5. With a height or surface gauge, check the distance between the face of the checking plate and each of the points marked off on the pencil lines drawn on the blade. Make a record of the blade and the distance at each point, for comparison with the other blade or blades.

6. Repeat the operations for each of the other blades.

Tolerance for Aluminum-alloy Blades.—The difference in track at any like points on aluminum-alloy blades must not exceed $\frac{1}{16}$ in. If the blade does not track within that dimension and the deformation is such as not to constitute an appreciable bend, the blade will be flexed or bent slightly at the proper point to restore its alignment within the specified tolerance.

Job Unit 55. Balancing of Propellers

Outline of Work.—If a balancing stand (see *A*, Fig. 210) is available, the instructor may introduce exercises in balancing the various types of propellers. See, for example, *Aeronautics Bulletin 7-H*, and manufacturers' instruction books.

Review Questions

1. Define blade angle, hub, blade, face, track, balance, plane of propeller, tip, shank.
2. How does a propeller develop thrust?
3. Name the types of stress loads on a propeller.
4. What is resonant vibration? Explain.
5. What is propeller flutter?
6. Why should scratches on a propeller receive immediate attention?
7. Why are scratches called "stress raisers?"
8. Why is fatigue stress in a propeller important?
9. Explain how to install an aluminum-alloy propeller.
10. How is propeller track measured?

References

1. Part 18, Civil Air Regulations, Maintenance, Repair, and Alteration of Certificated Aircraft, etc., Civil Aeronautics Administration, U. S. Department of Commerce, Washington, D. C.

2. "Handbook of Instructions for Airplane Designers," U. S. Army Air Forces. (Not available to the public.)

3. "Maintenance of Metal Propellers" and "Constant Speed Propellers," Hamilton Standard Propeller Company, East Hartford, Conn.

4. Instruction Book, Lycoming-Smith Controllable Propeller, Aviation Manufacturing Corporation, Williamsport, Pa.

5. Elementary texts on aerodynamics for study of aerodynamic theory.

Questions for Thought and Study of References

1. Why is a propeller blade thick at the shank?

2. Explain how to balance a wooden propeller.

3. Explain how to balance a metal propeller.

4. Explain the operation of a controllable-pitch propeller.

5. Explain the operation of a constant-speed propeller.

6. What is meant by efficiency of a propeller?

7. About what is the average efficiency of a metal propeller? Of a wooden propeller?

8. What is propeller slip? Slip ratio?

9. Define geometrical pitch of a propeller.

10. Which in general is greater, geometrical pitch or aerodynamic pitch?

CHAPTER XVI

SERVICING OF SHOCK ABSORBERS, BRAKES, AND TIRES

It is not practical to give, in this text, the instructions for servicing all makes of shock absorbers, brakes, and tires on the market. The different makes of each, however, have, in general, fundamental characteristics which are the same.

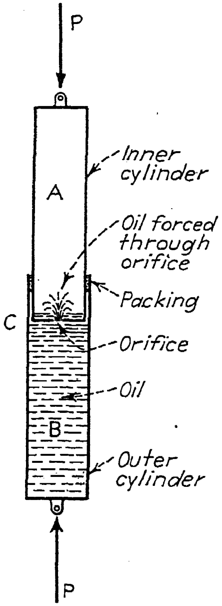

Fig. 217.—Absorbing (shock) energy by flow of oil through an orifice.

It is the purpose, in this chapter, to give these common fundamental characteristics, and then to give specific instructions, as outlined by the manufacturer, for the servicing of one or two makes of equipment. This arrangement will give the student training in the essentials.

In the shop, the manufacturer's instructions for the make of shock absorber, brake, or tire should be on hand and followed, for the most satisfactory service.

243. Shock Absorbers.—Shock absorbers, together with the tires, constitute the cushioning unit in landing and taxiing.

The principal elements of a shock absorber are as follows:

1. See Fig. 217. The landing load *P* forces the oil through the orifice *C* from cylinder *B* to cylinder *A*. This allows the strut to telescope, thus relieving the landing load and dissipating the energy without rebound.

2. When the cylinders in Fig. 217 have reached the limit of their telescoping, the strut no longer serves as a shock absorber. Thus, provision must be made for taxiing-shock absorption. Compressed air in chamber *A* or a coil spring in chamber *B*, or a combination of both, may be used for this (see Figs. 218, 219 and 220).

3. The rate of flow of the oil from one chamber to the other through orifice *C* (Fig. 217) determines the velocity of telescoping the strut. It is desirable

that this velocity of telescoping be regulated, during the stroke, to provide (with the tire) just the right amount of shock absorption. This is accomplished by regulating the *area of opening of the orifice* by means of a *metering pin* or *needle* of varying cross-sectional area which travels through the orifice during the stroke (see for example Figs. 218 and 220).

4. To prevent excessive rebound, the return flow of oil from one chamber to another is retarded (see for example the flap valve of Fig. 220).

244. General Service Rules for Shock Absorbers.—It is obvious that all shock absorbers should receive the following general service attention:

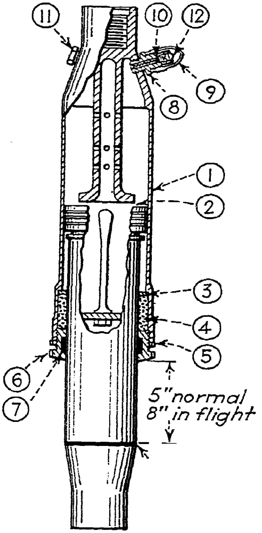

Fig. 218.—Aerol Oleo-Pneumatic shock-absorbing strut. (*Courtesy of Cleveland Pneumatic Tool Co.*)

1. The compressed air should be maintained at the proper pressure for satisfactory service.

2. The oil should be maintained at the proper level.

3. It is important that the right kind of oil be used. See manufacturer's recommendation, which is probably on a metal plate attached to the strut. If it is not, obtain from a representative, or from a local reliable aerosupply company.

JOB UNITS

Job Unit 56. Servicing Aerol Shock Absorbing Struts

Manufacturer.—The Cleveland Pneumatic Tool Company, Cleveland, Ohio.

Manufacturer's Instructions.—Service of Aerol Oleo-Pneumatic Strut (see Fig. 218).

Inflation Instructions.

1. Remove dust cap (No. 9) and valve cap (No. 12), then attach air hose to valve body.

2. Inflate with compressed air only until red line on piston tube (*A*) is approximately 5 in. below packing gland (No. 6). Move airplane forward and backward several times while inflating, to allow the wheels to take their normal position.

3. Check air valve inside (No. 10) to be sure it does not leak. Replace if necessary. Replace valve cap, and dust cap. The position of the aerol strut should be checked occasionally to insure equal inflation.

Repriming Instructions

1. Aerol struts should only be reprimed when there is an indication of oil leakage.

2. Deflate by pressing valve inside (No. 10) until strut is fully compressed. Remove the valve insides.

3. Remove primer plug (No. 11) and fill with Aerol Strut Oil.

4. Replace primer plug securely and replace valve insides. Inflate as per above instructions.

5. If there is any indication of oil leakage at gland (No. 6), loosen lock nut (No. 5), and tighten gland nut slightly.

Job Unit 57. Servicing Oleo-Spring Strut

Manufacturer.—The Cleveland Pneumatic Tool Company, Cleveland, Ohio.

Manufacturers Instructions.—Service of Aerol Oleo-Spring Strut (see Fig. 219):

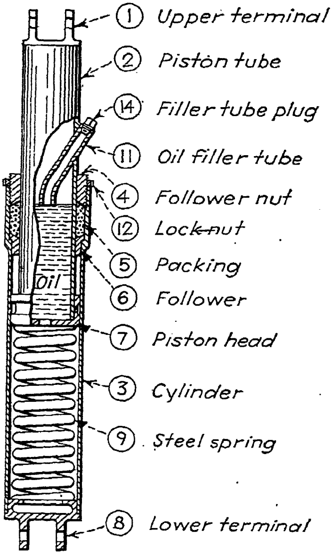

FIG. 219.—Aerol Oleo-Spring strut. (*Courtesy of the Cleveland Pneumatic Tool Co.*)

1. Aerol struts should be filled with oil occasionally. Fill struts with airplane at rest on level ground with no load. Remove plug (No. 14) and fill with Aerol Strut Oil.

2. If there is any indication of oil leakage by the packing, loosen lock nut (No. 12) and tighten follower nut (No. 4) then tighten the lock nut.

3. On all correspondence to the factory, be sure and advise type and serial numbers as indicated on the name plate.

Job Unit 58. Servicing Bendix Pneudraulic Shock Struts

Manufacturer.—Bendix Products Corporation, South Bend, Ind. Manufacturer's general maintenance instructions (see Fig. 220):

A. **Functioning.**—Benlix Pneudraulic shock-absorber struts are of the combined hydraulic and pneumatic type. *Impact loads* are dissipated mainly through the hydraulic unit by forcing fluid through the annular orifice, the size of which is controlled by the position of the metering pin in the orifice. Taxiing loads are carried mainly by the compressed air.

When the load comes on the strut and compression starts, the piston forces fluid through the orifice into the upper chamber where the rising fluid level compresses the air above it. When the strut has made sufficient stroke to *absorb the energy of the impact*, the air at the top expands and forces the fluid back. On the return stroke a valve, which is open on the compression stroke, is closed, and the fluid is forced back from one chamber to another through small holes. This acts as a snubber, preventing quick rebounds.

B. Fluid.—The fluid used in the Bendix Pneudraulic shock struts, called Bendix Pneudraulic Strut Fluid, is obtainable from the Bendix Products Corporation, South Bend, Ind. In the case of emergency, Standard Lockheed Brake Fluid No. 5 may be used for initial filling or for partial refilling. (The Bendix Strut Fluid should not be used for filling brakes.) Mineral oils must not be used, owing to possibility of packing deterioration.

C. Fluid Level.—Whenever the installation permits, the filler-plug boss is located on the centerline of the strut in the side view of the airplane in such a position that when fluid is just level with the hole in the boss, with the strut in the fully compressed position, the correct amount of fluid is indicated. Locating the hole in this position prevents possibility of error due to having the airplane in level landing as compared with three-point landing position for filling. If the installation does not permit this location of the filler plug, it becomes necessary to put in an extension tube from the filler plug boss to the center of the strut of such a length that when no more fluid can be added, the correct amount is indicated. Sometimes it is necessary to locate the filler-plug boss on the front of the strut or in some other position, which means that the strut must always be filled in one position—usually that taken by strut when tail wheel is on the ground.

There need be no definite inspection period for checking the fluid level in the struts. A certain amount of fluid loss, due to seepage past the packing rings, is to be expected and the fluid level in the strut will vary according to the amount of seepage, which may not be the same for any two struts. In general, however, the fluid level should be checked whenever the strut strikes bottom or top with ordinary usage when inflated to the proper extension. This indicates that the proportion of fluid to air has been decreased to a point where the air does not build up sufficient pressure to prevent bottoming. To check the fluid level, deflate the strut by depressing the valve core, then back off the filler plug one turn until all the fizzing of air and fluid stops. Remove the filler plug and check the fluid level. This level should be flush with the filler-plug hole when the strut is fully compressed.

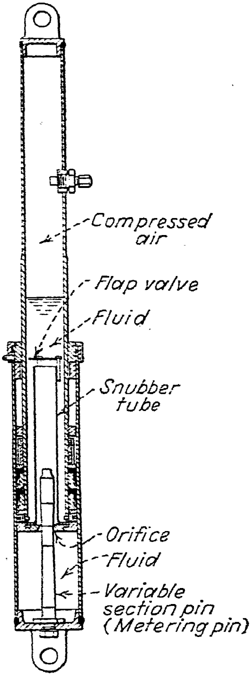

FIG. 220.—Bendix Pneudraulic shock strut, typical general arrangement. (*Courtesy of Bendix Products Corporation.*)

When a completely empty strut is filled, care should be taken completely to extend and compress the strut at least two times to make sure that all air pockets are eliminated before the final check for fluid level is made. This is unnecessary when fluid is added after the strut has been in service. If the strut is not in place on the airplane when it is filled, care must be taken to place it under the same angular conditions as on the airplane when final level is checked.

D. Inflation.—The actual air pressure required to inflate Pneudraulic shock struts depends upon the axial load on the strut due to the weight of the airplane and also on the friction due to the packing and any bending or torsional loads on the strut. These pressures vary from 200 to 800 lb. per square inch. Owing to the small quantity of air in the strut and the relatively high pressure required, *it is inadvisable to attempt to measure the pressure with a gauge.* This is unnecessary as the correct pressure is indicated when the specified extension of the strut is obtained under the full load. If it is more convenient to check pressures under a light load, the actual extension under this load should be noted after the strut has been properly inflated under the full load. The correct extension under full load is specified on the instruction plate.

Either a Bendix Booster Pump or high-pressure air bottle may be used for inflating struts. For first inflation the distance should be approximately ¼ in. greater than specified, as moving the airplane around will cause some absorption of the air by the fluid. A variation of ¼ in. either way for final reading should not be considered of importance. Adjustment should be made with the airplane out of the wind and without the slipstream from the propeller, and after the airplane has been moving forward, tail on the ground. The airplane should also be rocked occasionally while inflating to overcome packing friction, thus preventing inadvertent overinflation.

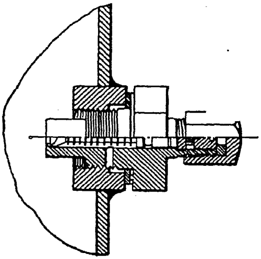
FIG. 221.

After the struts are once correctly adjusted, readjustments should not be made for minor changes, as these may be due to change in position of airplane, change of load, wind action, packing friction, rolling the airplane backward, etc. Always check only after airplane has been correctly loaded and has been rolled forward with tail down. Do not overinflate, as hard taxiing and bounce at contact will result.

The filler plug, which also contains the air valve, is provided with an annular ring on the under side of the hex. A soft copper gasket is provided between this ring and the plug seat on the strut. These seats must be free from dirt and marks, and the plug must be seated snugly to prevent air leaks at this point. If needed, a new gasket should be used each time the plug is replaced (see Fig. 221).

E. Air Valves.—Two types of air valves are suitable for use in these struts. Both are special types, developed for this purpose, one by Schrader's Sons and the other by Dill Manufacturing Co. These valves function like the ones in an automobile tire. The hex cap provided with this type of valve has a soft-metal seat to furnish a secondary seal. It should be screwed down tightly, but not so tightly that the tin seat in the cap is forced inward, thereby depressing the valve-core stem. The cores are replaceable.

The valve core and the seat around the filler plug should be tested for leaks by putting a little oil on these joints to show the presence of air bubbles. Mineral oil should not be allowed to reach the packing rings, as gumming may result.

If the air pressure is especially high, it is desirable to not overinflate struts as experience shows that the valve cores are more easily damaged by the releasing of high-pressure air through them than in any other way. Under the pressure ordinarily used, no difficulty results from this condition.

F. Packing.—The packing used in the Pneudraulic strut is a special aircraft packing, designed specially for this work. Two moulded composition rings separated by aluminum-alloy spacer rings are used. One type of design of the packing box requires rings with inside flexible sealing lips, and the other type requires rings with the flexible lips on the outside.

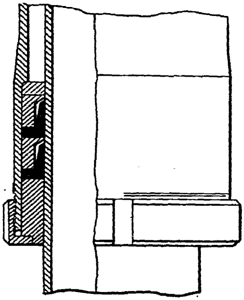

FIG. 222.

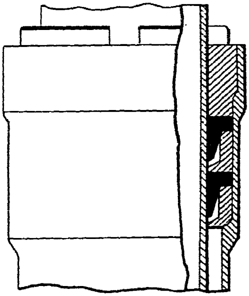

FIG. 223.

Sealing on the lip side of the packing is accomplished automatically by the hydraulic pressure; hence, any leakage on this side of the packing cannot be remedied by tightening down on the packing nuts. However, leakage past the fixed side of the packing can usually be eliminated by tightening down on the packing nut, as the heel of the ring is thus forced firmly against the packing-gland wall.

Packing rings, which will, of course, wear out in service, may be replaced as follows:

1. *Release all air from the strut by depressing stem of valve core.*
2. Remove filler plug and pour out fluid.
3. Unscrew nut at end of cylinder.
4. Pull out piston-tube assembly, if necessary, using a slight bumping action to break rings loose.
5. Study of this assembly will show how rings may be removed.
6. New rings should be installed in same manner as old ones.
7. After rings are installed, tighten packing nut down firmly to provide seal at heel of ring on side opposite lip.
   a. If the rings are of the inside-lip type, the packing nut is on the cylinder and is tightened down as the last assembly operation (see Figs. 222 and 223).

b. If the rings are of the outside-lip type, the packing nut is on the piston tube. It should be tightened down snugly before the piston-tube assembly is inserted in the cylinder. After the piston and rings are in the cylinder, but with the packing nut still outside, the nut should be tightened down firmly. In this case the nut at the end of the cylinder is used to prevent the strut from pulling apart (see Fig. 224).

Storage.—Struts should not be kept in storage in the inflated condition, except for short periods or when desired for immediate replacement, as the packing deteriorates as much when under air pressure in storage as in service. When struts are to be stored for long periods as spare parts, it is recommended that the inside be coated with a rust preventative, and that the struts be assembled without packing or fluid.

It is, of course, very important that the rust preventative be thoroughly cleaned out before the strut is provided with new packing, filled, and reassembled for service.

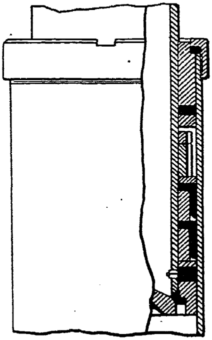

FIG. 224.

245. Airplane Brakes.

—These are of two types:

1. Mechanically operated brakes.
2. Hydraulically (oil-) operated brakes.

In general, airplane brakes are quite similar to automobile brakes in their operation, maintenance, and adjustments. Airplane brakes, however, are usually in two units, one unit for each landing wheel. This provides individual control for turning, taxiing, and landing.

The principal parts of an hydraulic brake are:

1. An oil line from the brake pedal to the brake for transmitting the braking impulse.
2. A master cylinder, the piston of which is connected with the foot pedal, where the oil-pressure braking impulse is developed.
3. A cylinder, bellows, or similar means for transmitting the braking impulse to the brake shoe.
4. A reservoir for keeping the system supplied with oil (braking fluid).

246. General Rules for Servicing Brakes.

—These rules are:

1. The brake shoe should be properly adjusted with respect to foot-pedal travel, so that the best braking conditions result.
2. The brakes should be maintained so that they always release properly, and so that they do not drag.
3. In hydraulically operated brakes, the oil system should be free from air. Air is removed from the system by bleeding the line; that is, by forcing oil through until all the air bubbles are forced out.

4. All mechanical parts of a brake should be kept free from water, as the brake will freeze up at high altitudes and lock in landing. This precaution is especially necessary for control wires operating in tubes.

JOB UNITS

Job Unit 59. Adjustment of Bendix Mechanical Brakes

Manufacturer.—Bendix Brake Co., South Bend, Indiana.

Adjustment Instruction for Mechanical Brakes Used with Roller Bearing Wheels.—These instructions apply to mechanical brakes employing the lever-type control, and Star wheel adjusting screw. *Bulletin* 19 covers instructions for other types of mechanical brakes used with roller bearing wheels.

1. Before attempting to adjust the brakes, jack up the wheel, and apply the brake several times to be sure the brake releases properly and promptly. If not, the hookup should be gone over carefully, all frayed spots in the cable corrected and pulley bearings lubricated until the brakes release rapidly to the full "off" position (see Fig. 225).

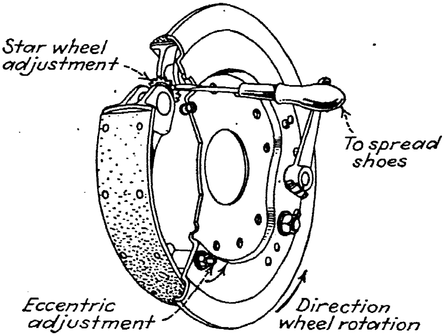

FIG. 225.—Mechanical brake. (*Courtesy of Bendix Brake Co.*)

2. Remove the wheel, inspect the brake for damaged parts and the brake lining for grease. If the lining is greasy, replace with new lining. If the brake shoe return springs do not have a good initial tension, they should be replaced.

3. Inspect the wheel bearings and remove any thin grease. Repack the bearings, using a small quantity of heavy graphite fibre grease, and renew the felt washer if necessary.

4. Replace the wheel and the wheel-bearing adjusting nut. Be sure there is no brake drag. Then, with the wheel spinning, tighten the adjusting nut slowly until a bearing drag on the spinning wheel is noticed. Back off the nut approximately one quarter turn and lock in position with a cotter pin. Brake drag should not be confused with bearing tightness while rotating the wheel during bearing adjustment. Replace the hub cap.

The brakes should now be adjusted as follows:

1. Loosen the eccentric lock nut and turn the eccentric in the direction of wheel rotation until the wheel is locked in position. Back off the eccentric until the wheel just rotates freely. With a close-fitting wrench hold the eccentric in this position and tighten the lock nut.

2. Uncover the adjusting-screw hole by rotating the cover plate and with a screwdriver turn the notched wheel of the adjusting screw away from the axle until a brake drag is noticed when turning the wheel by hand. Back off the notched wheel until there is no brake drag. Replace the cover plate.

NOTE.—On brakes using the Star wheel adjusting screw there is a positive stop provided for the actuated end of the primary shoe, which definitely sets the "off" position of this shoe. Therefore, no adjustment is necessary to the brake-control lever other than outlined under (3).

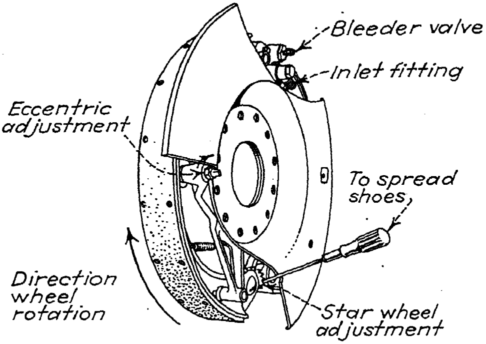

FIG. 226.—Hydraulic brake. (*Courtesy of Bendix Products Corporation.*)

3. The angle between the actuating rod or cable and brake lever should not be over 80 deg. when the brake is fully applied. This angle should be checked and corrected if necessary, but need not be changed if once corrected as the Star wheel adjustment entirely compensates for lining wear.

4. Owing to cable stretch, it may be necessary to adjust the operating cable sufficiently to bring the brake pedal into a position convenient for the pilot to operate it.

Job Unit 60. Adjustment of Bendix Hydraulic Brakes

Manufacturer.—Bendix Products Corporation, South Bend, Ind.

Adjustment Instructions for Hydraulic Brakes Used with Roller-bearing Wheels. Bleeding the Line.—Whenever the hydraulic line connecting the master cylinder to the brake cylinder is disconnected, air will be admitted to the system and the line must be bled to remove the air. This same condition may develop if the fluid reservoir becomes empty. Air in the line may be determined by the action of the brake pedal. If the brake pedal has a spongy action when applying the brake, the cause may be due to air compression in the system.

It will be noted from Fig. 226 that there are two fittings to the brake-actuating cylinder, namely, the inlet fitting and the bleeder. The bleeder is a needle valve with a cap or dust cover on the end.

To bleed the line proceed as follows:

1. Fill the reservoir with hydraulic-brake fluid, Lockheed No. 5. During the bleeding operation it may be necessary to check the fluid level in this reservoir several times, never allowing it to become empty.
2. Remove the dust cap or screw from the bleeder fitting.
3. Unscrew the bleeder valve one-half turn.
4. Prepare a piece of rubber tubing at least 12 in. long and slip one end of the tubing over the end of the bleeder fitting, allowing the free end of the tubing to hang in a receptacle.
5. Operate the brake pedal back and forth slowly; this action pumps fluid out of the reservoir and through the system. Continue this operation until the fluid from the hose connection on the bleeder is free of air bubbles. At least one pint of fluid must be pumped through the system before all air is removed.
6. Close bleeder fitting tightly and insert the dust cap.
7. Check the fluid in the reservoir, adding fluid if necessary.

Job Unit 61. Service of Goodyear Airwheel Hydraulic Disk Brakes

Manufacturer.—The Goodyear Tire and Rubber Co., Inc., Akron, Ohio.

A. Hydraulic Disk Brakes.—Goodyear hydraulic disk brakes are extremely simple, practically foolproof, powerful, smooth, and long-wearing. The mechanism is nothing more or less than a multiple disk, metal-to-metal clutch which functions as a brake.

This is accomplished by having bronze disks which are keyed to rotate with the hub fixed alternately with steel disks which are nonrotating, as they are keyed to the brake anchor bracket.

These disks are pressed together by means of a piston; and inasmuch as this piston is actuated by a fluid line connected directly to the brake pedal, proportionately as much braking power will be received as is applied to the pedal.

A master cylinder is installed in this fluid line, which provides the proper amount of pressure for the brake system. The proper linkage was provided by the airplane manufacturers' engineers so this master cylinder would build up the required fluid-line pressure from a proportionate amount of foot-pedal pressure. This master cylinder is, in reality, a pump, and it is kept supplied with fluid by gravity from a supply tank mounted usually just ahead of the fire wall.

When the brake pedal is applied, the piston in this master cylinder is mechanically moved ahead, thus creating the desired amount of pressure in the fluid line below the master cylinder, which pressure is directly transmitted to the wheel piston which then moves and presses the disks together.

When the plane is ready for delivery, the hydraulic brake system has been properly adjusted and bled so that there is no air in the entire system.

If there were any air in the system, this air would be compressed when the brake pedal is applied and no movement of the brake piston would result.

As delivered, the braking system should be good for a great number of normal landings, and it should not be necessary to add more brake fluid to the supply tank, rebleed the system, or replace any parts.

This statement assumes normal usage. Naturally, like anything else, unusual or continued severe usage of the brakes will demand inspections, replacements and adjustments of parts, which would not be necessary under normal brake usage.

If any dirt gets into the system, there is a possibility that small particles might destroy the complete seal of either the front or the rear master cylinder seal, or possibly the wheel piston seal, which would cause loss of fluid and possible entrance of air into the line.

If this should occur, it would only be necessary to flush the entire system, clean the two rubber seals in the master cylinder, or the wheel-piston seal if the leak is at the wheel, by washing them in alcohol. (Never use gasoline or oil on the rubber parts.)

It will then be necessary to bleed to eliminate all air from the system.

B. Bleeding the System

1. If it becomes necessary to bleed the system, the first step is to see that the supply tank is full of fluid.

2. Regular Lockheed No. 5 brake fluid is recommended for Goodyear airwheel disk brakes, and may be obtained from practically any service station.

3. *Bleeding with Air Pressure.*—The airplane factory may have provided a valve stem in the top of the supply tank. If so, attach an ordinary hand pump to this valve stem, remove cap screw from bleeder plug in the brake, and insert in its place a standard bleeder hose (obtainable from any garage).

Place the free end of the hose in a clean glass receptacle, back off the bleeder plug, and immediately start pumping. This will force the fluid through the system rapidly and pick up any air in the system.

Normally after about ¼ pint has come through into the receptacle, no more bubbles will appear and the system is then bled.

The bleeder plug should then be tightened and the cap screw with washer replaced.

Be sure to replace the valve cap on the reserve-tank valve. Otherwise, fluid might be lost in flight or dirt might get into the supply tank. Also make sure that the air vent in the valve cap is clear.

4. *Bleeding without Air Pressure.*—If the airplane manufacturer did not provide a valve stem in the supply-tank cover, bleed as follows:

See that the supply tank is full of fluid. Remove bleeder-plug cap screw and washer from bleeder plug in the brake and insert in its place a standard bleeder hose. Place the free end of the hose in a clean glass receptacle, shut off bleeder plug and then allow pedal to return to full off position slowly. This draws new fluid into the system from the supply tank.

Again back off bleeder plug, push down pedal rapidly, and after fluid stops flowing from hose, shut off bleeder plug. Allow pedal to return to full off position slowly.

Repeat this operation until no more air bubbles come from bleeder hose. Then shut off bleeder plug, remove bleeder hose, and replace bleeder-plug cap screw and washer. Check supply tank to make sure that tank is still at least half full of fluid.

5. Replace supply-tank cover. Otherwise, fluid might be lost in flight or dirt might get into the supply tank. Also make sure supply-tank-cover air vent is clear.

6. Dirt in the system might possibly clog the compensating part in the master cylinder. If this should happen, the pressure or volume on that particular brake could not be compensated and the brake would pump up through several strokes of the foot pedal, or owing to expansion from heat developed through use of the brake, and remain locked.

7. Locked brakes are impossible with a system which is clean and properly installed; but should this happen, remove the master cylinder, clean all parts of the cylinder, and be sure that the small compensating port ahead of the piston is not fouled.

8. Any garage in position to service hydraulic automobile brakes can service these master cylinders or bleed the system, as the principle in both is identical.

9. Naturally, the rotating bronze disks in the brake wear, and greater foot-pedal travel results. When the foot-pedal travel has become excessive, remove the wheel from the brake unit and take up on the disk adjustment and lock nut.

10. Screw the disk retaining and adjustment nut up tight, then back off until a $^{40}/_{1000}$-in. feeler gauge can be inserted between the disks. (This means for the entire set—not for each disk.)

11. Back off the disk retaining and adjustment nut to the next lock position (eight positions are provided) and install the lock spring, making sure to anchor it in the groove provided.

12. If the bronze disks are sufficiently worn, they should be replaced. New disks can be obtained from the airplane manufacturer or direct from Goodyear Aeronautics Department, Akron, Ohio.

13. Disks are easily applied by removing the wheel from the brake unit, removing the disk adjustment and lock nut, sliding the disks off the brake assembly, and replacing the alternate worn bronze disks with new ones.

14. Care should be taken to see that a bronze disk is installed next to the thick steel-pressure disk, and also that a steel disk goes on last, just before the adjustment nut.

15. When remounting the wheel on the brake unit, the keys extending from the bronze disks should all be lined up with a straight edge and the parking lever applied to hold them in that position. This will permit easy mounting of the hub on the brake assembly. If the keys are not held in position by the parking lever, the rotating bronze disks will move, and it will be extremely hard to center them in the slots in the hub ring.

Job Unit 62. Maintenance Hints[1]

A. Excessive Pedal Travel—Probable Cause

1. Normal wear of bronze disks.
2. Improper adjustment or clearance between disks.
3. *Leak in the system.*
4. *Air in the system.*
5. *Improper adjustment of length of master-cylinder piston rod.*
6. *Improper brake-pedal setting or linkage.*
7. *Lack of fluid in supply tank.*
8. *Vent in supply tank stopped up.*
9. *Improper bleeding—air mixed with fluid.*

Remedy.

1. As the bronze disks wear and become thinner, the brake piston must travel farther. This results in greater fluid displacement and consequently calls for greater pedal travel.

Remove wheel from brake unit. Remove retaining nut-lock spring from brake unit. Turn retaining and adjustment nut up tight. Then turn back until between 0.040 and 0.050 in. clearance is available. This can be determined by forcing a feeler gauge between the disks. (This means for the entire set—not for each disk.) Replace retaining nut-lock spring and lock in next lock point.

When bronze disks are so thin that further adjustment is impossible or condition calls for renewal, replace with new set of bronze disks.

2. The average adjustment for all sizes of brakes calls for 0.045 in. clearance between disks. This means for the entire unit, not for each disk. This can be measured with a feeler gauge.

3. If the pedal will gradually go clear on under pressure, there is a fluid leak in the system. Check out the leak.

4. A springy, rubbery action of the pedal indicates air in the system. An excessive amount of air in the system will permit the pedal to go full on under normal pressure. In either case the system should be bled.

5. If the master-cylinder piston rod was assembled and installed so that it was shorter than proper, excessive pedal travel would result. Refer to information under Master Cylinder Adjustment for proper setting.

6. This could not occur if the brakes functioned properly when the airplane was delivered. It could only occur owing to tearing down of the linkage, as during overhaul, and improper reassembling. Correct to original condition.

7. Air will enter the system if the supply tank runs dry. Supply tank should be checked at regular intervals and be kept at least one half full.

8. If vent in supply tank becomes stopped, there is a possibility of creating a vacuum in the supply tank so that fluid would not feed into the system by

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[1] These hints apply directly to Goodyear equipment. However, many of the hints will, in fundamental principle, apply to all brakes. The hints which have a probable general application are given in italics.

gravity. As a result, the lack of fluid in the system might permit excessive or full pedal travel without resultant brake operation.

Check the vent in the supply tank and see that it permits passage of air.

9. If too much air pressure is used when bleeding the system or the system is bled several times in a short period of time, the fluid may become full of small air bubbles. Either wait until air accumulates in large bubbles so it can be eliminated by bleeding, or drain and refill system with new fluid.

B. Dragging Brakes—Probable Cause

1. Improper adjustment or clearance between disks.
2. *Improper adjustment of length of master-cylinder piston rod.*
3. *Dirt in system.*
4. *Binding of brake piston or dust shield.*
5. *Use of improper fluid.*
6. *Weak or broken brake-piston return springs.*
7. *Weak or broken master-cylinder piston return spring.*
8. Dished or warped bronze or steel disks.
9. *Mechanical pedal linkage frozen.*
10. *Parking brake.*

Remedy

1. If disks are adjusted to provide more clearance than recommended, excess pedal travel will result.

If disks are adjusted to provide less clearance than recommended, expansion due to heat resulting from operation may cause dragging or even locked brakes.

See Remedy (1) under *A* for proper adjustment.

2. If master-cylinder piston rod is adjusted so as to be longer than proper, the compensating port would be covered and the system could not compensate. This might cause dragging brakes.

Dragging brakes from this cause may develop sufficient heat to expand the fluid to a point where the brakes would lock even though the brake pedal is in the full-off position.

If allowed to cool, the brake will function again, but the cause should be determined and corrected or the same condition would develop again.

If brake locks out on the field, open the bleeder plug at the wheel. This will release the pressure and the ship can be taxied from the field. However, cause should be determined and corrected before operating further, as otherwise the same condition would occur again.

3. Dragging or locked brakes may be due to dirt in the system, particularly in the supply tank. Such dirt might clog the compensating port in the master cylinder and dragging or locked brakes, as described in *B* (2), would result.

Dirt in the system may also get under the rubber seals in the master cylinder or under the wheel-piston seal and cause leaks, as described in *A* (3).

If dirt is found in the system, remove both master cylinders and dismantle the brake assemblies. Then flush supply tank and lines thoroughly with No. 5 Lockheed fluid and bleed.

4. Dust and dirt mixing with brake fluid at the wheel piston may become gummy and may cause sticking of the wheel piston or even cause air leaks. Parts should be removed and thoroughly cleaned in alcohol. Then reinstall as before.

5. Improper fluid may not operate properly under severe heat or cold conditions. Improper fluid may destroy rubber seals in master cylinders or at wheel piston or cause swelling of rubber seals with resultant closing of the compensating port. In such case, replace with new seals, flush system thoroughly with alcohol, and fill and rebleed with No. 5 Lockheed fluid.

6. If brake-piston return springs are broken or weak, the brake piston would not return to full-off position or would move slower than proper. Consequently the returning fluid would move sluggishly and the usual feel of the brake would be lacking. This might also cause dragging or locked brakes. Replace with new springs.

7. If master-cylinder return spring is weak or broken, the master cylinder piston will not move back against piston stop and the compensating port would not be cleared. Results would be as described in *B* (2). Remove and replace with new springs.

8. Dished or warped disks seldom occur. However, if disks are discovered to be in this condition, remove them and place them on a flat plate and tap until they return to flat condition. Then reinstall.

If impossible to correct or if disks have become too badly worn from operating in this condition, they should be replaced with new disks.

Dished or warped disks would change the clearance or adjustment, and dragging brakes might result.

9. If mechanical linkage is frozen up, it might be impossible for the master cylinder to operate properly, even though the brake pedal is in full-off position. Check out and free up the point of trouble.

10. Parking devices improperly installed or adjusted may cause dragging brakes owing to the fact that master-cylinder piston is not permitted to return against piston stop even though foot pedal is in full-off position. Check out this possibility. Results would be as described in *B* (2). The parking device should be adjusted or interference cleared so that master cylinder can operate properly.

Job Unit 63. Mounting and Demounting Low-pressure Airplane Tires on Drop-center Rims

NOTE: As recommended for Boeing 247.

A. Mounting Instructions

1. Examine wheel flanges. Remove any sharp burrs with a file. Mount first bead of casing on wheel at the side opposite brake drum. Method of application is a button-holing process, the necessary slack being obtained by keeping the applied part of bead as far into the well of rim as possible. Use a flat, thin, smooth ended tool if necessary.

2. Remove core from valve in tube and evacuate practically all the air. Replace valve core and insert tube in casing with valve stem pointed outward and positioned adjacent to the valve hole in the rim. Inflate tube until it is well rounded out but not stretched. Work the tube over the flange, preferably using a hammer as a tool, holding the hammer head in the hand and pushing the tube with the end of handle progressively around the tube. Position valve stem at hole and pull up with rim nut, as there is great danger of pinching tube when mounting second bead.

3. Mount second bead as instructed in (1), progressing around bead in short advances. Do not sink tip of tool far under casing as there is danger of injuring tube.

4. Inflate to 25 lb. pressure and tighten valve-stem rim nut.

B. Demounting Instructions.

1. Remove rim nut and valve core. Allow tube completely to deflate.

2. Loosen tire beads from both sides of wheel.

3. Remove bead from rim on the valve side of wheel using two thin flat, smooth-ended tools. The methods of removing is a buttonholing process, the necessary bead slack being obtained by keeping the part of bead not yet removed from the rim as far into the well as possible.

4. Remove tube making sure that there are no sharp burrs on the rim flange.

5. Remove second bead from the wheel as described in (3).

Job Unit 64. Mounting and Demounting General Streamline Airplane Tires

Manufacturer.—General Tire and Rubber Co., Akron, Ohio.

A. Mounting

1. Soap the bead ledges of the rim, and the tire beads, with a good vegetable-oil soap. This not only aids in mounting, but the soap acts as a lubricant, allowing the beads easily to slide clear out to an accurate bead seat against the rim flange as the tire is inflated.

2. Place the inside bead of the tire only (without the tube) across the outside flange of the rim, with the red dot on the casing near the valve hole.

NOTE: The outside flange is the one on the valve-hole side.

3. Start the bead over the rim flange by pounding on the inside of the tire, using a wooden block of suitable length (see Fig. 227). Continue pounding around the tire until all of the inside bead drops over the rim flange.

4. Dust the entire surface with soapstone or talc.

5. Insert the tube in the casing, as shown in Fig. 228, with the valve stem at the red dot in the casing. Reach in between the tire bead and the rim and insert the valve stem through the valve hole. Apply rim nut loosely to hold valve stem in place.

NOTE: All tires are mounted on a balance stand and checked for balance at the factory. Any heavy spot will revolve the tire until the heavy spot comes to rest at the bottom. The position of the light spot directly opposite is marked with a red dot. By placing the valve stem of the tube at this dot the weight of the valve stem tends to counterbalance the heavy spot of the tire which is directly opposite, providing as perfect a balance as possible.

6. Inflate the tube slightly to shape it. Do not inflate tube enough to fill the casing.

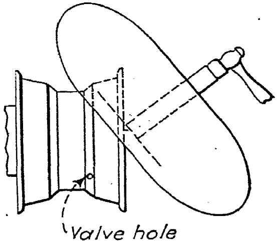

FIG. 227.—First step mounting tire.

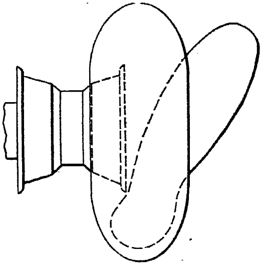

FIG. 228.—Second step, inserting tube.

7. Beginning opposite the valve stem, use a bar to start the outside bead over the rim flange. Finish mounting by using a wooden block, and pound the bead over the rim, as shown in Fig. 229.

8. Inflate the tube with an abnormal amount of pressure to seat the beads. Remove the valve inside and fully deflate the tube, but be sure to leave both tire beads properly seated on the rim. Replace valve inside, and again inflate slowly to the required pressure. Tighten valve rim nut.

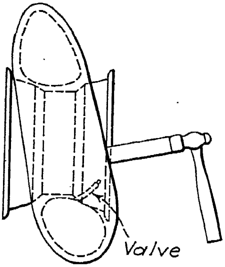

FIG. 229.—Third step in mounting tire.

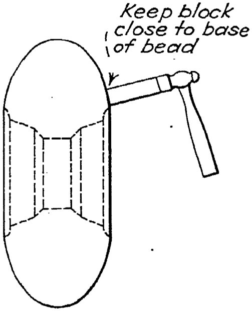

FIG. 230.—First step in demounting tire.

9. It may be necessary again to check for balance. This can be done on the stub axle if the bearings are perfectly free. If not, the complete assembly should be mounted on a balance stand. Locate the heavy spot of the assembly. Add weight to the wheel, directly opposite this heavy spot, until the assembly is in perfect balance and will not revolve from any fixed position.

B. Demounting

1. Let all the air out of the tube and remove rim nut. After tube is completely deflated, pound both the front and back beads loose from the rim, using a wooden block (as shown in Fig. 230). Keep the block against the lip of the rim flange, otherwise the blow will tend to tip the bead, making it stick tighter than ever.

2. With a small bar, pry the outside bead over the rim flange at the valve stem (see Fig. 231). Be sure the bead of the tire is down in the rim well, opposite the valve stem, to provide the necessary clearances. Continue to pry around the tire until the outside is off the rim.

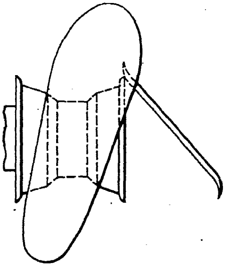

FIG. 231.—Second step in demounting tire.

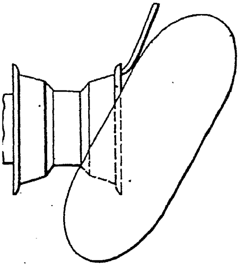

FIG. 232.—Third step in demounting tire.

3. Remove rim nut from valve. Take valve out of the rim and remove tube from casing.

4. With a bar start one side of the inside bead out over the outside flange. If it is so tight that it cannot be pried off, the bead may be pounded over the rim flange from the back, using a wooden block. (See Fig. 232.)

Review Questions

1. Name the essential parts of a shock absorber.
2. Name the essential parts (*a*) of an hydraulic brake; (*b*) of a mechanically operated brake.
3. Explain how to bleed the oil line for an hydraulically operated brake.
4. What is the effect of air in the line of a hydraulic brake?
5. State three general causes for dragging brakes.
6. State three general causes for excessive pedal travel.
7. Explain how to remove a streamlined airplane tire.
8. Explain how to fill an Aerol strut with oil.
9. Explain how to fill a Bendix Pneudraulic shock strut with oil.
10. Explain how to adjust a mechanical brake.

References

1. "Technical Information of Airplane Products," The Goodyear Tire and Rubber Co., Inc., Aeronautics Dept., Akron, Ohio.

2. "Airplane Brakes," Bendix Brake Co., South Bend, Ind.

3. "Aerol Oleo-Pneumatic and Oleo-Spring Shock Absorbing Struts for Aircraft," The Cleveland Pneumatic Tool Co., Cleveland, Ohio.

4. "Bendix Disk Wheels and Brakes for Aircraft," March, 1935, Bendix Cast Streamline Airplane Wheels and Brakes," October, 1935, and "Bendix Pneudraulic Shock Struts," by Bendix Products Corporation, Airplane Wheel and Brake Division, South Bend, Ind.

5. *Tire Engineering*, November, 1934, General Tire and Rubber Co., Akron, Ohio.

6. "Maintenance and Service Manual, Boeing Model, 247," by Boeing Airplane Co., Seattle, Wash.

7. "Aeronautical Accessories and Technical Service," by B. F. Goodrich Rubber Co., Akron, Ohio.

Question for Thought and Study of References

1. Why should tubes which house brake-operating wires be sealed against water?

2. How would you find out the pressure required in the tire of an airplane you are servicing?

3. How often should shock struts, brakes, and tires be inspected?

4. How will a locked brake affect the landing of an airplane?

5. Name all the causes for locked brakes, and state all the remedies for each cause.

6. What is the effect of the loss of air pressure in a shock absorber?

7. What is the effect of the loss of oil in a shock absorber?

8. What would be the effect of action of a shock strut of using a heavy oil or oil which becomes "stiff" when cold?

9. Why should grease never be put in a shock strut?

10. What information is usually given on the name plate of a shock strut?

APPENDIX

SAMPLES OF TROUBLE AND INSPECTION REPORTS

To enable the student mechanic to become familiar with this phase of repair shop routine, the following sample trouble and inspection reports are appended:[1]

1. Airplane Trouble Report.
2. Airplane Inspection Report.
3. Propeller Inspection-repair-installation Record.

AMERICAN AIRLINES, INC., TROUBLE REPORT[2]

1. Station__________Date__________Report Number__________
2. If Enroute AM______Trip______ { Interrupted Flight No.____ } Delay:
   Date__________ { Station Delay No.______ } Hrs.____Mins.____
3. Airplane NC______MFGR.__________
   Total Time______Time Since Overhaul______Time Since Inspection______
4. Part Causing Trouble__________
   Manufacturer of Part______Model__________MFG. No.__________
   Time Since Last Thorough Inspection of Part______Total Time on Part______
5. If Engine Part or Accessory—Left( ); Center( ); Right( ); Eng. No.______Time Since Major Inspection______Since Overhaul______Total Time______
6. If Personnel: Name__________Station__________Penalty__________
7. If Trouble Occurred at Some Other Station: Station__________Date______
8. Description of Trouble and Damages__________
9. Probable Cause of Trouble__________
10. Trouble Chargeable: Poor Workmanship( ); Poor Insp.( ); Poor Design( ); Defective Material( ); Length of Serv.( )
11. Action Taken
    At Station:
    Installed Parts MFGR. No.__________New( ); Used( ) __________
    Disposition of Unsatisfactory Parts__________
    __________To Station__________C-44 No.__________
    __________To Station__________C-44 No.__________
    Recommendations for Preventing Recurrence__________
    Signed Mech.__________Approved Chief Mech.__________Date__________
12. Comments Supervisor of Maint.__________
    __________Signed__________Date______
13. O'Haul Foreman:
    Cause of Trouble__________
    Disposition of Parts__________
    Recommendations__________
    __________Signed__________Date______
14. Action Office Supt. of Maint.__________
    __________Signed__________Date______

Courtesy of American Airlines, Inc. H.D.

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[1] The first three of these reports are by courtesy of the American Airlines, Mr. H. D. Ingalls, Superintendent of Maintenance; and the fourth is by courtesy of Aero Insurance Underwriters, Mr. Jerome Lederer, Chief Engineer.

[2] The blank writing spaces have been condensed.

AMERICAN AIRLINES, INC.—AIRPLANE INSPECTION REPORT

Station________ Date________193____ Airplane________ D.O.C. No.________
Engine Numbers L________ C________ R________ Hub Nos. L________ C________ R________

DAILY INSPECTION	
Fuselage structure	
Wing structure	
Control surfaces, cables, pulleys, and horns	
Check tail-wheel assembly, grease and align	
Check heater for leaks and control and fill water tanks	
Check ventilating system	
Drain gas-tank sumps and strainers and safety	
Check wheels, tires, brakes, etc.	
Check all instruments and connections	
Check landing gear and flap-signal system	
Refill hydraulic-fluid reserve tank	

Check main battery		Check aux. battery	
Clean airplane		Clean wheel wells	

GROUND TEST		ENG.	LEFT		CENTER		RIGHT	
Fuel in tanks		Gal.						
Oil in tanks		Qt.						
Max. oil temp.		°F.						
Engine speed		Rpm	Max.	Idle	Max.	Idle	Max.	Idle
Oil pressure		Lb. sq. in.	Max.	Idle	Max.	Idle	Max.	Idle
Boost pressure		In. hg.	Max.	Idle	Max.	Idle	Max.	Idle
Fuel pressure		Lb. sq. in.	Max.	Idle	Max.	Idle	Max.	Idle
Generator		Amp.						
Ignition								
Vacuum pump	Gyro.	In. hg.						
	Art. horiz.	In. hg.						
	Turn & B'nk	In. hg.						
Ground time		Min.						

Check oxygen equipment and pressure	
Check de-icer installation	

ENGINES	L	C	R
Engine mounts			
Cowling and supports			
Fuel system drained and checked			
Oil system			
Engine controls			
Ignition system			
Propellers checked and greased			
Carb. Heater and controls			
Clean cuno strainers			

RADIO	
Antennas, etc.	
Power units	
Transmitter	
All receivers	
Headsets and micro'nes	
Jacks and switches	
Controls and accessories	

Radio ramp tested at AM PM with
and certified in working condition
Airplane inspected at AM PM and
Certified airworthy
Engines inspected at AM PM and
Certified airworthy
Engines ground tested at AM PM and
Certified airworthy

Engines inspected by L
C
R

Airplane inspected by

ELECTRICAL SYSTEM	
Wiring control box to battery	
Booster coil and wiring	
Battery box and connections	
Ignition wires and shielding	
Check and repair lights and fuses	

Emergency tool kit	
First-aid kit	
Motor covers	
Hand crank	
Blind-flying equipment	
Automatic pilot	

MAJOR INSPECTION	L	C	R
Control valves and controls			
Inspection of propeller blades for cracks and nicks			
Valve adjustments, lock nuts and adjust screws			
Rocker arms—bearings or bushings			
Intake and exhaust manifold—leaks, nuts, and gaskets			
Starter and attachment bolts and nuts			
Gasoline lines—fuel pumps and connections			
Primer lines—connections and mountings			
Oil-tank heaters and connections			
Drain and check oil sumps and screens			
Check oil radiator—leaks and mountings			
Exhaust manifold and intensifier tubes			
Change spark plugs			
Check compression on all cylinders			
Check cylinder hold-down studs			
Check oil tanks—leaks, caps, and mountings			
Oil drained (Qt.)			
Oil added (Qt.)			
Magneto hold-down bolts			
Adjustment of breaker points			
Grease starter outboard bearings			
Clean and oil air maze			
Engines washed			
Check all gas and oil hose			
Magneto bearings oiled			
Fire-extinguisher lines and mountings			
Overhead oiling system and control valve			
Vacuum pumps, lines, and mountings			

Check oleos for oil and inflate	
Remove wheels for brake inspection	
Lubricate all landing-gear fittings	
Check landing-gear trunnions with indicator	
Check bungee cord Douglas	
Door locks and seat belts	
Cabin chairs and upholstering	
Inspect complete heater system	
Inspect heater thermostats	
Windows, windshields and latches	
Stabilizer and flettner controls	
Wing and aileron covering	
Gas tanks—leaks, caps, vents, and gauges	
Release Flares—mechanism—date of mounting	
Department of commerce card and date of expiration	
Elevator, aileron, and rudder hinge pins, bearings, and brackets	
Elevator, aileron, and rudder controls	
Vertical-fin and stabilizer attachment fittings	
All ribs, struts, wires, and fittings	
Clean and grease flap rear-piston-rod bearing	
Test and operate landing gear	
Inspect flap system and attachments	
Inspect landing-light brackets	
Remove wing bands for inspection	
Venturis—Check and clean	
Pitot static horn—check and clean	

Chief mechanic

PROPELLER INSPECTION-REPAIR-INSTALLATION RECORD

*Inspection-repair Record*__________ Station__________
Received from__________ Hub Design No.__________ Serial No.__________
Removed from Airplane NC__________ Engine Serial No.__________ L ☐ C ☐ R ☐
Received on Stock Transfer No. Last Installation Record No.

Condition before Servicing
Date Received__________ Propeller Diameter______ Ft.______ In. Track__________
Base Setting__________
*General*__________
Blade Design Stations High Low

No.			18	24	30	36	42	42	48	54	60	66
Blade Serial Number	1	Angle°										
		Width										
		Thickness*										
	2	Angle°										
		Width										
		Thickness*										
	3	Angle°										
		Width										
		Thickness*										

Condition after Servicing * Last Three Stations
Date Completed__________ Propeller Diameter______ Ft.______ In. Track__________
*General*__________
Blade Design

No.			18	24	30	36	42	42	48	54	60	66
Blade Serial Number	1	Angle°										
		Width										
		Thickness*										
	2	Angle°										
		Width										
		Thickness*										
	3	Angle°										
		Width										
		Thickness*										

Base Setting__________ * Last Three Stations
Hub Plated______ Blades Etched Or Magnafluxed______ Straightened______
List All Hub Parts Replaced__________
Disposition__________ Date__________ Reference__________
Remarks__________

Time Since Inspection______: Total Time Hub______: 3. ______:______
Total Time Blades 1. ______: 2. ______:______

APPROVED__________ SIGNED__________ PROPELLER DEPT.______

INITIAL AIRCRAFT INSPECTION REPORT[1]

1. POWER PLANT INSPECTION L C R
2. Engine, make and h.p.________________________
3. Time since major overhaul________________________
4. When are engines major overhauled?__________By whom?__________
5. When is oil changed?______________Grade of oil__________
6. When are propellers inspected for pitch, track, cracks, nicks?__________
7. How often are carburetor wells cleaned?_____Fuel Strainers?_____Air Screens?_____
8. At what intervals are periodic inspections made? Source of information (Log Book)?__________
9. ENGINE NACELLES (If airplane is multi-motored use the letters L C R to denote which engine you refer to)
10. Are they clean, do they show care and attention?______________
11. Are engine mount, ring, bearers and fittings sound (welds O.K.; bolts tight and safetied; loose rivets; corrosion; any cracks in fittings)?______
12. Any cracks, corrosion, or loose or injured members on fuselage or wing structure adjacent to the engine mount fittings?_______Are engine fittings firmly attached to fuselage or wing?____________________
13. Is cowling in good condition and securely mounted?_____Shutters?_____
14. Are rubber vibration dampeners oil soaked or otherwise deteriorating?________________________
15. ENGINE ASSEMBLY
16. Are crank case and cylinders in good condition (Any cracks in crank case; lugs; any oil leaks; water leaks; are cylinders and bolts secure; are spark plugs clean and secure; fins whole; are cylinder heads sound)?_____ Are ignition wires properly attached to plugs?________to mags?______
17. Is ground wire secure and in good condition?_____Are the wires in good condition (insulation not worn; no cracks; not oil soaked, not rubbing anywhere)?_____Shielding in good condition?_____Are tachometer_____ Oil temperature_____Water temperature_____Manifold pressure_____Fuel pressure_____Connections secure and in good condition?____________
18. Are the generator cables in good condition and securely attached?_____ Booster mag. leads?_____
19. Are engine accessories securely mounted and safetied; Gas pumps_____ Carburetor_____Generators_____Oil pumps_____Oil radiator_____Booster mag._____Magnetos_____Vacuum pumps_____Carb. heater_____Starter and other solenoids_____Tach generator_____Constant-speed unit_____Water radiator?_____
20. Intake manifold (cracks, bolts tight)_______Exhaust manifold (cracks, bolts, corrosion)_______
21. By pass valves_____Fuel strainers_____Induction tubes_____Baffles_____
22. Are stacks burned through or thin?_______Oil strainers_______Other accessories_______
23. Is carburetor drain open?_____Does it lead gas away from exhaust?______

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[1] This report is an excellent one to follow in general inspection of airplanes.

24. Are fuel lines and connections (and primer lines) in good condition?____ Do they require annealing?____Are bends properly made?____How often are they annealed or changed?______Are lines insulated from engine vibrations?______(NOTE: inspect lines particularly where they go through fire wall).
25. Are oil lines and connections in good condition?____Water-pump packing satisfactory?____
26. Are oil and fuel lines prevented from rubbing?______Any likelihood of oil or gas dripping on ignition system or on exhaust system or electrical system?____Is the oil tank securely mounted?____Any cracks in vicinity of oil-tank fittings?______Elsewhere on tank__________
27. Is oil drain safetied?____Is oil cap tight (gasket)?____Are fuel valves securely mounted?____Any leaks?____Is bonding satisfactory?____
28. Are the engine controls secure (clevis pins cottered, no interference, no binding) Throttle______Spark____Carb. heater______Altitude____Carburetor____Shutters____Prog. speed____Other?__________
29. Is fire wall in good condition?______Any holes?______
30. Any signs of corrosion in vicinity of battery?____Any corrosion below battery?________
31. Is the battery securely mounted?______Is the battery container adequately ventilated?______Are the battery cables properly attached?____
32. Is battery clean?______What type of cabin and cockpit heater is used (exhaust, steam, electric)?______Can it be taken apart for inspection?______When was this last done?______Is there a permanent fire extinguisher installed for engine fires?____Type?________Is extinguisher full?______Tubing O.K.______
33. Orifices clean?______Does tubing extend around carburetor?____Is propeller in good condition (Nicks, clean, hub bolts tight, tight on shaft, open seams)?______________
34. COCKPIT
35. Is cockpit clean?______Do you smell gas?____Are windows in good condition?______Do windows open and lock easily?______Are pilot's seats and belts firm and secure?________When was compass last swung and compensated?______By whom?________
36. COCKPIT CONTROLS
37. Are the engine controls secure?______Do they operate properly: Throttle ______ Spark ______ Shutter ____ Heater ____ Altitude ____ Propeller____Radiator____Friction locks?______
38. Is the instrument board secure?______Are the instruments apparently in good condition (no broken glass, hands pointing properly)?______Oil thermometer____Air speed____T and B indicator______
39. Manifold press____Vacuum gauges____Tachometer____Altitude____ Compass____Air thermometer (should read temp. of outside air)____ Other?____By whom are they serviced?______
40. Is the sensitive altimeter connected to static side of pitot tube?________ Is pitot tube heated?________
41. Are the connections to instruments satisfactory?______Are control wheels or stick secure and connections cottered?______Are rudder bar

or pedals securely mounted and rudder brake cables or tubes properly connected and safetied?______Are bell cranks, sprockets, pulleys, fairleads in cockpit firmly and securely mounted and in good condition?_____ Do flight controls function satisfactory (any binding, any looseness, rubbing or interference) Aileron_____Elevator_____Flaps_____Rudder_____ Tab or stabilizer_____Brakes?_____

42. Do fuel valves operate properly?______Are fuel gauges working?_____ Are switches secure and tight?_____Any spare fuses?_____
43. Main switch O.K.?______Is electric wiring satisfactory?_____Do navigation lights work_____landing lights_____instrument lights?_____Is flare-release mechanism properly installed?______Has it been tested?______ Are emergency exits in operating order?_____
44. Is fire extinguisher full?_____Tested?_____Bracket secure?_____
45. Does undercarriage retracting mechanism work satisfactory?_____Has undercarriage been droo-tested recently?_____Is undercarriage warning indicator allright?_____Radio controls O.K.?_____
46. FUEL TANKS
47. Are fuel tanks securely mounted?_____Are connections and tubing in good condition?______When were sumps drained?_____Any cracks in vicinity of fittings, (fuel line, gauges, drains)?_____Are drains safetied?_____Is filler cap secure?_____Is strainer safetied?_____Are vents open?_____Dump valves convenient?_____
48. CONTROLS
49. Follow through control linkage for security and condition of brackets, pulleys, bellcranks, fairleads, condition of control cables or tubes at bearing points, safetying of turnbuckles and connections, cottering of clevis pins, wear at bearings and connections, fraying of cables.
50. Condition of rudder controls_____Aileron_____Flap controls_____Brakes _____Fire extinguisher_____Dump valve_____Elevator_____Stabilizer or tab_____Flare_____Aileron rudder and stabilizer tab controls_____Other controls_____Undercarriage retracting mechanism_____Is spare fuse box accessible______
51. CABIN
52. Is cabin clean?_____Windows O.K.?_____Any odor of fuel?_____Are seats and belts firm and in good condition?_____Can passengers interfere with controls?_____Is door secure?_____Is first-aid kit available?_____Are steps and hand grips secure?_____Is fire extinguisher full?_____Bracket secure?_____Are radio receiver, transmitter and generator securely mounted?_____Are ventilators and heaters in good condition?_________
53. AIRPLANE STRUCTURE
54. Is airplane clean, is general appearance good, fair, untidy?________
55. Any excessive oil on belly of fuselage?_____Is fabric oil soaked?_____Is exhaust dangerously close to fabric?______
56. FUSELAGE
57. What is condition of fuselage structure at wing fittings and at wing strut attachment fittings?______
    At undercarriage attachment fittings?_____At engine attachments?_____ At tail-surface attachments?_____At tail-skid attachments?_____

58. Are any of these fittings loose?______Do they show wear in bearings? ____Have you rocked the airplane to check these items?____
59. Are the bolt and pins safetied?____
60. Is the fuselage covering in good condition (rivets, seams, fabric tightness, any broken fairing strips)?______
61. Is cowling in good condition and securely mounted?____
62. Is inside of fuselage clean?______
63. Is structural condition satisfactory, (corrosion, members true to shape)? ______Any wrinkles in skin?____or fabric?____
64. Are drain holes open (Monocoque design?____Any debris in rear of fuselage?____
65. WINGS (Use letters LU, LL, RU, RL, CS to denote left upper, left lower, right upper, right lower and center section).
66. Spars: Are main attachment fittings satisfactory (loose, corroded, rusty, do bolts fit snugly; safetied; any wear in bearings)?______Are spars in good condition adjacent to the fittings?______Elsewhere?______
67. Are strut fittings in good condition on spar?____On struts?____Any wear in strut fitting bearings?______Any cracks in strut fitting lugs?____ Are strut pins and bolts safetied?____Are struts in good condition (no nicks, bend, rust or corrosion)?____
68. Are flying wires in good condition, especially where they cross landing wires?______Landing wires?______
69. Are lift struts and fittings in good condition?______
70. Are strut and wire clevis pins cottered or bolts locked?______
71. Are drain holes in wing open?________
72. Any broken rib?____Is covering in good condition (any open seams, cracks, tears, loose rivets, loose nails, corrosion)?______Any wrinkles in covering?________
73. Is leading edge in good condition?______Is Drag trussing tight?____
74. Are aileron hinges secure?______Any play in aileron hinges______Are aileron control bellcranks, tubes or cables securely attached, and binding?____ Are ailerons in good condition, horns secure?____Are hinge pins safetied?____Are aileron struts in good condition?____Tabs?____Are flaps securely mounted and in good condition?____
75. Is operating mechanism clean and secure?____Are landing and navigation lights secure?____Retractable landing lights?____
76. If wings fold, is locking device secure and in good condition?____
77. UNDERCARRIAGE
78. Are shock struts of equal length ____Any play in bearings of chock struts?____Other struts?____Are fittings attaching struts to wing or fuselage in good condition?____
79. Are any fitting welds covered by fairing when inspected?____Are fittings at wheel end of struts in good condition (Any nicks, bends, corrosion in struts)?____
80. Are tires and wheels in good condition?____Are brake connections satisfactory?____
81. Is undercarriage cowling secure?____Brakeshoe springs and mechanism?______

82. If retractile, are wells clean, any leaks in hydraulic system?____Is retracting mechanism clean?____Is condition of retracting mechanism satisfactory?____Is it properly lubricated?____
83. TAIL WHEEL
84. Is chock strut in satisfactory condition?____Tail wheel?____Are limit wires satisfactory?____Are fittings in good condition?____Any evidence of strut having damaged adjacent structure?____
85. TAIL SURFACES
86. Are brace struts securely attached and ends safetied?____Are they in good condition?____Are hinge pins cottered?____Are hinges tight?____ Are horns securely attached?____Are turnbuckles or tube ends safetied?____Are clevis pins on horn cottered?____
87. Is covering in good condition?____Does internal structure appear to be satisfactory? ____ Fin? ____ Rudder? ____ Stabilizer? ____ Elevator?____Is fin firmly attached and safetied at front fitting?____Are fin fittings and adjacent fuselage structure satisfactory?____Is front connection of stabilizer firm?____Are stabilizer fittings and adjacent structure satisfactory?____Any serious dents in (lower) strut?____In leading edge of stabilizer?____Is bottom of stabilizer and bottom of fuselage around tail in good condition?____Is elevator tab secure and in good condition?____Rudder tab?____Any play in stabilizer control mechanism?____
88. MISCELLANEOUS
89. Are radio antenna securely attached?____Radio loop?____De-icers?____
90. Do log books show periodic inspection of airplane?____Does insured have a mechanic to inspect and make repairs?____Submit Mechanic's History Card.
91. Is this airplane equipped for instrument flying?____Has this inspection been made at request of a dealer?____Who represented the insured?____ His attitude towards your commendations?____What is the airplane to be used for?____

INDEX

A

Absorbers, shock, servicing of, 322
Acetylene, dissolved, 111
  generated, 109
  safety precautions for, 111
Acetylene gas, 108
Acetylene generator, 107, 110
Acetylene tanks, 111
Aging of aluminum alloys, 81
Ailerons, 24
  parts of, 32
  static test of, 43
Air Commerce Regulations, questions on, 5
Aircraft maintenance welding, 105
Aircraft parts, failures of, 94
Aircraft welds, classes of, 106
  proportions of, 138
Aircraft wires, 279
Airplane, center of gravity of, 41
  controls of, 24
  electrical installations of, 30
  equipment of, 20
  fuel system of, 29
  fuselage of, 24
  heating system of, 30, 36
  instruments of, 29
  nomenclature of, 20
  oil system of, 29
  parts of, 20
  power plant of, 28
  propellers of, 28
  radio equipment of, 30
  soundproofing of, 31
  static and dynamic testing of, 40
  structural strength, maintenance of, 188
  structural types of, 20
Airplane, ventilating system of, 30
  wings of, 20
Airplane mechanic, education of, 2
  examination questions for, 5
  knowledge of structures, 3
  qualifications of, 1
  responsibility of, 1
  specialized training of, 2
  technical skill of, 2
Alclad, 80
Aluminum, sheet, welds in, 181
  spot welding of, 157
  welding of, 152
    table of variables for, 159
    types of joints, 154
Aluminum alloy, aging of, 81
  Alclad, 80
  annealing of, 78
  anodizing of, 79
  bending of, 14
  care of, 14–16
  cast, dendritic structure of, 93, 94
  cleaning surfaces of, 301
  cooling rates of, 81
  dendritic structure of, 93
  drilling of, 14
  identification of, 16, 102
  propellers, care of, 308, 309
  properties of, 72
  rivets, heat treatment of, 228
  sheet-metal structures of (*see* Thin-sheet-metal structures)
  strength of welds in, 159
  table of heat soaking of, 80
  thin-sheet-metal structures of, 243
  used in bumping, 220
  welding of, 154
Aluminum-copper alloys, critical-range diagram of, 76

Aluminum-magnesium alloys, table of properties of, 71
Annealing, of aluminum alloys, 78
  of bumped metal, 221
  full, 77
  of metals, 77
  normalizing, 78
  stress relief, 77
Anodizing aluminum alloys, 79
Approved repair stations, 7
Arc, electric, use of, 151
Arc welding, currents for, table of, 151
  protection in, 132
  of stainless steel, 162
Ash, 273
Assembly hangar and equipment, 8
Automatic pilot, 26

B

Back-pressure valves, 116
Backfiring, of welding blow torches, 120
Backward welding, 144
Balance, of propellers, 311
Balanced control surfaces, 25, 26
Balancing of propellers, 320
Band saws, 14
Basic stresses, 189
Beading rolls, 14
Beam, forces in, 199
  parts of, 200
  trussed, 200
  webs of, 204
    assumed not to buckle, 204
    assumed to buckle, 203
    thin, 201
  wing, repair of members of, 249
Bending, of beam, 199
  of fuselage, 207
  of members, 66
  of sheet metal, 14
Bending test, of metals, 66
Biplane, 22
Birch, 273
Blackjack, bumping, 213
Blowpipes, welding, 118
Box beams, 205
  stiffness of, 206
Box wing beams, 205
Brakes, 328
  Goodyear disk, 331
  maintenance hints on, 334
  mechanical adjustment of, 329
  servicing of, 322
    rules for, 328
  sheet-metal, 14
Brazed joint, 180
Brazing, 164
Brinell hardness test, 63
Buckling, 189
  of struts, 209
Bulkheads, 192
  rigidity of, 195
Bulletins of Bureau of Air Commerce, 3, 4
Bumped metal, annealing of, 221
Bumping, aluminum alloys used in, 220
  dies for, 215, 217
  forms for, 216
  hand, 218
  of metals, 213, 214
  mold for, concrete, 216
  sandbags for, 214
  of sheet metal, 212
  of structural parts, 221
  wooden forms for, 216

C

Cable, Navy splice in, 288
  preformed, 280
  Roebling splice in, 291
  soldered terminal in, 286
  True-Lay aircraft, table of, 282
Cadmium plating, 98
Calcium carbide, 109
Carburizing, 79
Casein glue, 274
Center of gravity, of airplane, location of, 41
Chassis, 26
China Clipper, 29
Civil Aeronautics Administration, 3

Cleaners, care of, 300
Cleaning, aircraft, 296
  of Alclad surfaces, 301
  of fuel tanks, 304
  of fuselages, 304
  glass, 303
  of hangar floors, 302
  of interiors of airplanes, 302
  of oil tanks, 304
  practices in, 303
  of shop floors, 302
  types of, 296
Clevis pins, 283
Cluster weld, 179
Compression, 189
Compression members, 66, 209
Compression test, of metals, 66
Connection, wing, 207
Control surface, balanced, 25, 26
  repair of leading edge of, 263
Control surface locks, 32
Control wires, 25
  static test of, 44
Controls, of airplane, 24
Cooling rates, of aluminum alloys, 81
Cord, aircraft 7 × 7, 280
    table of, 281
  7 × 19, 280
    table of, 282
Corrosion, of metals, 61
    in welds, 145
Corrugated sheet metal, 190
  repair of, 246
  standard, allowable stress in, 247
Cowling, cracking of, 198
Critical-range diagram, of aluminum-copper alloys, 76
  of steels, 75
Currents, for arc welding, table of, 151
Cutting sheet metal, 13, 14
Cutting tips, 128
Cutting torches, 128

D

Decarburization, 96
De-icers, 32
Dendritic structure, of aluminum alloy, 93
Dies, bumping, 215
Dinging hammers, 213, 214
Direct-current welding, 129
Dissolved acetylene, 111
Dolly blocks, 214
Dope, and fabric rooms, 10
  kinds of, 276
Doped surfaces, cleaning of, 301
Doping fabric surfaces, 276
Douglas DC3-178, heating system of, 36
  parts of, 27
Douglas fir, 273
Drilling aluminum alloys, 14
Drop hammers, 219
Ductility of metals, 59
Durability of metals, 61
Duralumin, effect of overheating of, 96
    (*See also* Aluminum alloy)
Dynamic testing, 40
  of landing gear, 55

E

Edging rolls, 15
Elastic Stop Nuts, 240
Elasticity, modulus of, 57
Electric arc, use of, 151
Electric tack welding, 152
Electric welding, 129
  table of current and electrode sizes for, 151
Electrical installations, 30
Electrode size, for arc welding, table of, 151
Elevators, 24
  static test of, 46
Endurance limit, of metals, 60
Engine covers, 32
Engine mount, 198
Engine-mount cover, cracking of, 198
Engine nacelle, repair of, 271
Equipment, of airplanes, 20
  of assembly hangar, 8

Equipment, cleaning of, 297
  heat-treating, 11
  welding, 17
  of welding shop, 105
Etching aluminum alloys, 93

F

Fabric, aircraft, 275
  patching, 278
  seams in, 276
  stitches in, 276
Fabric rooms, 10
Fabric surfaces, doped, cleaning of, 301
  doping of, 276
Fabric work, equipment required in, 275
Failure, of aircraft parts, causes of, 94
  of metals, 65
  of repairs, causes of, 146
  of stringers, 197
Fairchild 24, M-C-8E, parts of, 27
Fatigue failure, 41
Fatigue resistance, of metals, 60
Fatigue test, of metals, 67
Ferrous materials, table of properties of, 68
Ferrules, 279
  table of, 281
Filler rod, handling of, 173
Fins, horizontal, 25
  static test of, 47
  vertical, 25
Fire-fighting equipment, 32
Fire-fighting system, 37
Flames, welding, 123
Flaps, wing, 33
Flares, 32
Flash welding, 132
Flexibility, of structure, 208
Floats, seaplane, repairing of, 265
Flux, removal of, 155
Flux-coated welding rods, 131
Fluxes, welding, 123
Flying boat, 29
Forming sheet metal, for repairs, 212
Forward welding, 144
Fuel system, of airplane, 29
Fuel tanks, cleaning of, 304
  welded, repair of, 155
Full annealing, 77
Fuselage, airplane, 24
  cleaning of, 304
  repair of, 253, 257
  semimonocoque, 30, 207

G

Gas, acetylene, 109
  hydrogen, 112
Gas regulators, 113
  nozzle type, 115
  preparation for using, 116
  two-stage, 114
Gas welding, equipment for, 106, 107
Gas welds, 106
Gases, for aircraft welding, 108
Generated acetylene, 109
Generator, acetylene, 107, 110
Glass, cleaning of, 303
Glue, 274
  casein, 274
  mixing of, 274
  splicing with, 275
  spreading of, 274
Gluing, 274
Goggles, welding, 108
Goodrich Rivnuts, 238
Government regulations, 3
Grain size, of metal, 76

H

Hammers, bumping, 213
  dinging, 213, 214
  drop, 219
  sheet-metal, 212
  smoothing, 214
Hangar floors, cleaning of, 302
Hard surfacing, 160
  methods of, 160
  preparation for, 160
Hardening of metals, 78

Hardness, measurement of, 62
  of metals, 62
Hardness test, Brinell, 63
  Rockwell, 64
  scleroscope, 63
Heading rivets, 235
Heat-treated aluminum alloys, welding of, 154
Heat-treatment cycle, 75
  effect of composition on, 81
  effect of welding on, 137, 141
  equipment in, 11
  of metals, 73
  precipitation, 76
  temperature control of, 81
Heating system, of airplane, 30, 36
Hooke's law, 57
Horizontal fins, 25
Hose, welding, 121
Hydrogen, safety precautions for, 112
Hydrogen gas, 112
Hydrogen tanks, 107

I

Ice removal, 32, 37
Identification, of aluminum alloys, 16, 102
  of metals, 16
Impact test, of metals, 66
Inspection of propeller, sample of record, 344
Inspection report, sample of, 345
Instruments, of airplane, 29

J

Jig saws, 14
Jigs, welding, 169
Job units, ix
Joints, butt-riveted, 241
  lap-riveted, 240
  riveted, failure of, 227
  types of, 223

L

Landing gear, 26
  dynamic testing of, 55
Lathe, screw-cutting, 15
Leading edge, of control surfaces, repair of, 263
  of wing, repair of, 262
Longeron repair, 168

M

Macro test, 91
Magnaflux detection of defects, 91
Magnaflux methods, 89, 138
Maintenance cleaning, 296
  of metals, 74
  of propellers, 306
Major repairs, 3
Mallets, bumping, 213
Manifolds, welding of, 117
Members, compressive buckling of, 209
Metallic arc, characteristics of, 130
  theory of, 130
Metallic-arc welding, 129
Metallic-arc welds, 106
Metallurgy, welding, 138
Metals, annealing of, 77
  bending test of, 66
  bumping of, 213, 214
  carburizing of, 79
  care of, 16
  compression test of, 66
  construction of thin sheets of, 188
  corrosion of, 61
    in welds, 145
  critical range diagram of, 75
  defects in, 88
    detection of, 88
    microscopic detection of, 91
  ductility of, 59
  durability of, 61
  effect of overheating of, 95
  elasticity of, 57
  endurance limit of, 60
  fatigue resistance of, 60
  fatigue test of, 67

Metals, grain size of, 76
  hardening of, 78
  hardness of, 62
  heat treatment of, 73
  identification of, table of tests for, 86
    tests for, 85
  impact test of, 66
  improper distribution of, 97
  maintenance of, 74
  marking of, 16
  microscopic inspection of, 91
  nitriding of, 79
  nonferrous, table of properties of, 70
  properties of, 57
    radiographic study of, 67
    tables of, 68–71
  sheet, bending of, 221
    bumping of, 212
      forms for, 217
      hand, 218
      power, 219
    bumping dies for, 215
    filing of, 212
    forming of, for repairs, 212
    grinding of, 212
  strength of, 57
  structure of aluminum alloy, 243
    thin sheet, types of repair of, 243
      (*See also* Thin-sheet-metal structures)
  tempering of, 78
  tension test of, 66
  testing of, 66
  toughness of, 59
  types of failure of, 65
  ultimate strength of, 59
  uneven heating of, 95
  uses of, 57
  warpage of, 95
Microscopic inspection, of metals, 91
Microtest, 91
Modulus of elasticity, 57
Monocoque fuselage, 30
Monocoque structure, holes in, 187
  illustration of, 191
Monocoque structure, theory of, 190
  wrinkling of, 193
Monocoque wing beams, 205
Monoplane, braced, 21
  cantilever, 21
  high-wing, 21
  low-wing, 22
Multispar monoplane wing, 206

N

Nacelle, engine, repair of, 271
Nacelle skin, cracking of, 198
Neutral welding flame, 125
Nibbling machine, 15
Nitriding of metals, 79
Nomenclature, 20
  propeller, 306
Normalizing, 77
Nozzle-type regulator, 115
Nut, Elastic Stop, 240
  self-locking, 240

O

Office space, in repair shops, 8
Oil system, of airplane, 29
Oil tanks, cleaning of, 304
  welded, repair of, 155
Oleo-spring strut, servicing of, 324
Overheating, of steel, 77
Oxyacetylene welding flames, 123
Oxygen, 108
  safety precautions in use of, 109
Oxygen tanks, 107
Oxyhydrogen welding flames, nature of, 126

P

Parker-Kalon screws, 237
Patching, fabric, 278
Physical testing, of metals, 66
Pilot, automatic, 26
Pine, white, 273
Power plant, of airplane, 28
Propeller, record, sample of, 344
  steel, care of, 316
  stresses in, 307

Propeller track, checking of, 318, 319
Propellers, 28
  aluminum-alloy, care of, 308
  assembly of, 311
  balance of, 311
  balancing of, 320
  inspection of, 344
    daily, 309
    periodic, 312
  maintenance of, 306
    daily, 309
  major repair of, 313
  nomenclature of, 306
  operating adjustment of, 314
  periodic overhaul of, 312
  types of, 308
  vibration of, 316
Properties, of aircraft steels, 67
  of aluminum alloys, 72
  of ferrous materials, table of, 68
  of metals, 57
Proportions, of aircraft welds, 138
Protection, in arc welding, 132

R

Radio equipment, 30
Radiographic study of metals, 67
Regulators, gas, 107, 113
  nozzle-type, 115
  preparation for use of, 116
  two-stage, 114
Reinforcing rings, 192
  rigidity of, 195
Repair failures, causes of, 146
Repair shops, assembly hangar, 8
  dope rooms in, 10
  equipment of, 7
  fabric rooms in, 10
  office space in, 8
  sheet-metal, 12
  stock room of, 16
  welding equipment for, 17, 105
Repair stations, approved, 7
Repair weld, 180
Residual strains, 78
Resistance welding, 106, 132
Retracting mechanism, of landing gear, 34
Rib lacing, 276
Ribs, of wing, 23
    repair of, 271
Ring, reinforcing, 192
Rivet gun, 236
Rivet set, 237
Riveted joint, butt-, 241
  failure of, 227
  lap-, 240
  strength of, 229
  test for strength of, 241
  types of, 223
Riveters, air pressure of, 14
Riveting, 223
  excessive pressure in, 95
  rules for, 234
  stainless-steel, 229
  of tubes, 233
  types of, 231
Riveting tools, 236
Rivets, 223
  Al7ST, table of, 230
  Alclad, 24S, table of, 231
  duralumin, 17S, table of, 232
  heading of, 235
  heat treatment of, 228
  removing of, 244
  snap, 236
  Thomson, 225
  types of, 223
Rivnuts, Goodrich, 238
Rockwell test, 64
Rods, flux-coated, 131
  welding, 121, 140
Rudder, 24
  static test of, 47
Rules for riveting, 234

S

Safety precautions, for acetylene, 111
  for hydrogen, 112
  for oxygen, 109
Sandbags, for bumping, 214
Sawing sheet metal, 14

Saws, band, 14
  circular, 15
  jig, 14
Scleroscope hardness test, 63
Screws, Parker-Kalon, 237
Seam welding, 133, 158
Seams, in fabric, 276
Seaplane, parts of, 23
Seaplane floats, repairing of, 265
Semimonocoque structures, 195
Shackles, 283
  table of, 284
Shaping of steel, by burning, 127
Shear, definition of, 189
  in thin web of beam, 202
Shear members, 66
Shears, squaring, 14
Sheet metal, aluminum alloys used in bumping, 220
  bending of, 130
  brakes, 14
  buckling of, 189
  bumping of, 212
    forms of, 215
    hand, 218
    power, 219
  bumping dies for, 215
  care of, 12
  corrugated, 190
  cutting of, 13
  engine mounts, 198
  filing of, 212
  forming of, by hydraulic press, 219
    for repairs, 212
  grinding of, 212
  hammers, 212
  power forming of, dies for, 220
  sawing of, 14
  shear, throatless, 15
  structural types of, 191
  wrinkling of, 190
Sheet-metal shop, 12
Sheet-metal structures, 188
  repair of, 243
  semimonocoque, 195
  shear loads in, 198
    (*See also* Thin-sheet-metal structures)
Shock absorbers, service rules for, 323
  servicing of, 322
Shop, cleaning floors of, 302
  welding equipment for, 105
Shops and equipment, 7
Shrinkage, of welds, 147
Silver soldering, 163
Soundproofing, of airplanes, 31
Spar, wing, repair of flange of, 260
Spar web, repair of, 259
Spars, stressed skin, 205
  of wing, 23
Splice, Roebling, 291
Splicing wood, 275
Spot welding, 132
  of aluminum, 157
  of stainless steel, 164
Spruce, 273
Squaring shears, 14
Stability, 189
Stabilizer, repair of, 263
  static test of, 46
Stainless steel, arc welding of, 162
  riveting of, 229
  spot welding of, 163
  welding of, 161
Static test, of aileron, 43
  of control wires, 44
  of elevators, 46
  of fin, 47
  of rudder, 47
  of stabilizer, 46
  of wing beam, 203
  of wing rib, 48
Static testing, 40
  of engine mount, 54
  principles involved in, 41
  of wings, 49
    of leading edge, 53
Steel, cutting of, with gas flame, 127
  effect of heat on, 101
  effect of overheating of, 96
  with nitrides present, 140
  overheating of, 77
  properties of, 67
  shaping of, by burning, 127
Steel propellers, care of, 316

Stock room, 16
Strain, 57
  residual, 77
Stress, 57
Stress-relief annealing, 77
Stress-strain curve, 59
Stressed skin, of fuselage, 207
  of wing beams, 205
    (*See also* Thin-sheet-metal structures)
Stresses, basic, 189
  in propeller, 307
  in thin webs, 202
  in torsion, 193
Striking tools, 213
Stringers, failure of, 197
  repair of, 251
  strength of, 196
  typical sections of, 195
Structural parts, bumping of, 221
Structural tests, scope of, 40
Structural types, of airplanes, 20
  of sheet metal, 191
  study of, 33
Structures, sheet-metal, flexibility of, 208
  monocoque, theory of, 190
  of thin sheet metal, semimonocoque, 195
    (*See also* Thin-sheet-metal structures)
Struts, buckling of, 209
    of fixed ends, 210
  repair of, 166, 249
  replacement of, 251
  shock-absorbing, servicing of, 323, 324
  tubular, repair of dent in, 271

T

Tail wheels, 26
Temperature control, in heat treatment, 81
Tempering, of metals, 78
Tension, 189
Tension members, 65
Tension test, of metals, 66
Terminal fittings, 283
Testing of metals, 66
Tests for identifying metals, 85
Thimbles, aircraft, 282
    table of, 283
Thin-sheet-metal structures, cleaning of, 301
  preparing of, for repair work, 245
  repair of, 243
    of cracks in, 256
    of fuselage of, 257
    of highly stressed members of, 245
    minimum equipment for, 243
    removing rivets for, 244
    of small holes in, 255
    of smooth-stressed skin, 248
    of stabilizer of, 263
    of vertical fin of, 263
    of web of wing spar of, 259
Thomson rivets, 225
Tip sizes, for aluminum welding, table of, 149
  for brazing and hard surfacing, 149
  for oxyacetylene welding of steel, table of, 149
Tips, cutting, 128
Tires, demounting of, 337
  mounting of, 336, 337
  servicing of, 322
Tools, riveting, 236
Torches, backfiring of, 120
  cutting, 128
  welding, 107, 118
    balanced-pressure type, 118, 120
    injector-type, 119
Torque tube, repair of, 270
Torsional stresses, 193
Toughness of metals, 59
Transport airplane, parts of, 25, 27
Trouble report, sample of, 341
Trussed beam, 200
Tubes, repair of, 165, 166, 168
  riveting of, 233
  riveting to, 233
  torque, repair of, 270

Tubes, welding of, 177, 178
Turnbuckles, 283
  table of, 284

U

Ultimate strength of metals, 59
Undercutting, 98
Uses of metals, 57

V

Valves, back pressure, 116
Ventilating system, 30, 36
Vertical fins, 25
  repair of, 263
Vises, 13
Vought Corsair V-80, 23

W

Warpage, in aluminum welds, 150
  in magnesium welds, 150
  in welds, 147
Web of beam, stresses in, 202
Welder, requirements for, 105
Welding, 105, 147
  alignment, 174
  of aluminum, 152, 157
    table of variables for, 159
  of aluminum sheets, 181
  backward, 144
  of corners, 175
  direct-current, 129
  electric, 129
  of fish plate, 183
  flame, neutral, 125
    oxyacetylene, 123
    oxyhydrogen, nature of, 126
  flash, 132
  fluxes, 123
    removal of, 155
  forward, 144
  gas, 106
    equipment for, 107
  gases for, 108
  goggles, 108
  hard surfacing method of, 160
Welding, heat, application of, 150
    effect of, 137, 141
  of heat-treated aluminum alloys, 154
  hose for, 121
  jigs, 169
  of manifolds, 117
  metallic-arc, 106, 129
  metallurgy, 138
  methods, 137
  of motor-mount ring, 183
  resistance, 106, 132
  rods, 121, 140
    flux-coated, 131
  room equipment, 17
  seam, 133, 158
  spot, 132
  of stainless steel, 161
  torches, 107, 118
  of tubes, 177, 178
  of tubular members, 165
  of types of aluminum joints, 154
  wire, 108
Welding blow torch, backfiring of, 120
Welds, aircraft, typical proportions of, 138
  in aluminum alloys, strength of, 159
  application of heat to, 143
  classes of, 106
  cluster, 179
  considerations for making sound, 143
  corrosion in, 145
  examination of, 137
  metallic-arc, 106
  rosette, 176
  shrinkage of, 147
  warpage of, 147
    in magnesium, 150
  washer, 176
  X-ray study of, 139
Wing, airplane, 20
  beams of, box, 204, 205
    fundamental parts of, 200
    repair of flange of, 260
    shell-type, 205

Wing, beams of, single-spar, 206
    static test of, 203
    stiffness of, 206
    stressed skin, 205
    with thin webs, 202
    trussed, parts of, 200
    web of, repair of, 259
      stresses in, 202
  connection, 207
  flaps of, 25, 33
    repair of, 263
  leading edge of, repair of, 262
  material of, 22
  multispar, 206
  ribs of, 23
    repair of, 271
    static test of, 48
  single-spar, 206
  spar, 21, 23
    repair of members of, 249
  split flap of, 34
  static test of, 49
  trailing edge of, repair of, 258
Wire structures, repair of, 273
Wires, aircraft, 279
  aircraft cord, 7 × 7, 280
    table of, 281
  7 × 19, 280
    table of, 282
Wires, hard, 279
    loop terminal in, 284
  Roebling splice in, 291
  soldered terminal of, 286
  tinned aircraft, table of properties of, 280
  welding, 108
Wooden structures, repair of, 273
Woods, aircraft, table of properties of, 273
  in aircraft structures, 273
  characteristics of, 274
  composition of, 274
  compression failure of, 274
  diagonal and spiral grain of, 274
  method of sawing of, 274
  moisture content of, 274
Wrinkling, 190
  of monocoque structure, 193
  of thin sheet metal, 190

X

X-ray detection of metal defects, 88
X-ray study of weld, 139

Y

Young's modulus of elasticity, 57